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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM 1372

DROP HAMMER TESTS WITH THREE OLEO STRUT MODELS AND THREE DIFFERENT SHOCK STRUT OILS AT LOW TEMPERATURES

By Kranz

Translation of "Fallhammerversuche mit drei Ölfederstrebenmustern und drei verschiedenen Federstrebenölen bei tiefen Temperaturen." Deutsche Luftfahrtforschung, Untersuchungen und Mitteilungen Nr. 564, ZWB, Berlin-Adlershof, Jan 17, 1939.

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DROP HAMMER TESTS WITH THREE OLEO STRUT MODELS AND THREE DIFFERENT SHOCK STRUT OILS AT LOW TEMPERATURES*

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ABSTRACT

Drop hammer tests with different shock strut models and shock strut oils were performed at temperatures ranging to -40° C. The various shock strut models do not differ essentially regarding their springing and damping properties at low temperatures; however, the influence of the different shock strut oils on the springing properties at low temperatures varies greatly.

OUTLINE

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*"Fallhammerversuche mit drei Ölfederstrebenmustern und drei verschiedenen Federstrebenölen bei tiefen Temperaturen." Deutsche Luftfahrtforschung, Untersuchungen und Mitteilungen Nr. 564, ZWB, Berlin-Adlershof, Jan. 17, 1939.

A. OCCASION AND PURPOSE OF THE INVESTIGATIONS

On instigation of the Reichsminister for Aviation (RLM - letter: LC II No. 1449/37, 1 z.b.V. of Apr. 15, 1937) drop hammer tests with oleo-shock struts at low temperatures were started.[1] These tests were occasioned by failures found on landing gears with oleo-shock struts at low temperatures. The tests were to determine, for certain shock-strut models and shock-strut oils enumerated below, at what temperatures the shock-strut forces increase so much that danger arises.

Moreover, the tests were extended in the direction of finding a shock-strut oil that would not cause a significant increase of force in the shock strut at a temperature of -40° C and would still possess sufficient lubricity. For this purpose, we performed, aside from the drop hammer tests at various temperatures, also friction tests in the compression press which provided information on the lubricating qualities of the various oils.

In the drop hammer tests performed at temperatures between +20° C and -40° C, the following shock-strut models and shock-strut oils were investigated:

(1) VDM oleo-pneumatic shock strut, model 400, for airplane models W 33/34, manufactured by the Vereinigten Deutschen Metallwerken A.-G., Frankfurt (Main)-Heddernheim.

(2) EC oleo-pneumatic shock strut, model 320, for airplane models W 33/34, manufactured by the Elektron-Co m.b.H. at Stuttgart-Bad Cannstadt.

(3) Arado oleo-rubber shock strut for airplane model Ar 81, manufactured by the Arado-Flugzeugwerke G.m.b.H., Brandenburg (Havel).

- (a) Shock-strut oil "Shell AB 11," obtained from the Rhenania-Ossag A.-G., Hamburg.
- (b) Shock-strut oil "Vacuum 'S' 2069," obtained from the Deutschen Vacuum-Öl-A.-G., Hamburg.
- (c) Blue hydraulic fluid "DMB" obtained from the Dornier-Werke G.m.b.H., Friedrichshafen a.B.

The cross-sectional drawings of the three shock struts mentioned are represented in figures 1 to 3. The VDM shock strut (fig. 1) and the EC

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[1]The tests and their evaluation were carried out by Messrs. Kieback and Mucha.

shock strut (fig. 2) are oleo-pneumatic shock struts where compressed air is used as a springing medium and oil is used for increase of the energy absorption and damping; the Arado shock strut (fig. 3) is an oleo-compressed rubber shock strut in which rubber rings, which are compression-stressed and connected in series, serve as springing media.

In their oleo-component, the three shock struts are of completely different construction; in the VDM shock strut (fig. 1), the oil present in the hollow piston rod is - when the strut is deflected - forced by means of a disk piston connected with the cylinder head, thru several longitudinal slots in the piston-rod wall graduated in length and open toward the inside, and therefore divided into several individual jets. The EC shock strut (fig. 2) uses, for displacement of the oil from the hollow piston rod, a slightly conical plunger so that a circular cross section is available for the discharge of the oil from the piston rod. In the Arado shock strut (fig. 3), the oil present in the cylinder is displaced by a tightly fitted disk piston with central opening from which one passageway leads into the hollow piston rod and two further passageways into the annular space between piston rod and cylinder wall. Whereas, in the VDM and EC shock struts, the cross section for the passage of the oil decreases with increasing strut deflection; in the Arado shock strut this cross section remains constant during the entire stroke.

The shock-strut oils mentioned above are pure mineral oils, partly made into fatty oils and graphited, of low fluidity which are manufactured especially for use in oleo-shock struts and hydraulic actuators for airplanes (landing-gear retracting devices, landing-flap actuators, etc.). The composition of the oils used is known only in case of the DMB fluid. According to the patent specification of Aug. 15, 1936, the DMB fluid consists of a mixture of hydrocarbons (for instance paraffin oils or vaseline) with hydrogenation products of naphthalene. The oils were investigated with respect to viscosity-temperature curves, specific weights, pour point[2], and solidifying point by the Institute of Fuel Research of the DVL; the results of this investigation are represented in the following viscosity temperature chart (fig. 4).

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[2]Definition of the pour point: Instructions for purchase and examination of lubricants, Benth publishing house.

TABLE I

Designation of oil	Pour point °C	Solidfying point °C	Specific weight at 20° C
a Shell AB 11	-61.5	-61	0.868
b Vacuum S 2069	-65	-62	.891
c Dornier DMB	below -73		.874

For the friction tests in the compression press oleo-pneumatic shock struts of the construction type VDM were used; for vertical loading of the vertical shock strut under the effect of low temperatures, the VDM shock strut model 400 represented in figure 1 was selected, whereas for vertical loading of the oblique shock strut at room temperature, a cantilevered VDM shock strut, model 700, was used; the latter corresponded in its internal construction to model 400 apart from larger dimensions and a greater guide length of the piston rod. In the friction tests in the compression press, the following oils and oil mixtures were investigated aside from the oils enumerated above; they are indicated, with their pour point, in the following numerical table.

TABLE II

Designation of oil	Pour point °C	Specific weight at 20° C
d Shell V 50806	-67	0.895
e Mixture c + d in ratio 1:1	below -73	.885
f Mixture c + d in ratio 1:2	about -73	

The Shell oil V 50806 is, according to data of the Rhenania Ossag A.G., a mineral oil made very fatty which has a very high lubricity. The viscosity-temperature curve of this oil together with the oil types enumerated in table I (row a to c) is represented in the viscosity-temperature chart (fig. 4). The viscosity-temperature curves of the mixtures e and f are not plotted in figure 4; they lie between curves of oils c and d.

From the fact that the pour point of the two mixtures e and f lies even lower than at -73° C one may conclude that at temperatures down to -40° C when these mixtures are used for oleo-shock struts, no essential increase in force is to be expected. Regarding the lubricity of these mixtures, test results are given in a later section.

B. TEST ARRANGEMENT

1. Cold Test in the Drop Hammer

The drop hammer tests were carried out with a drop hammer weight corresponding to half the reduced mass of the airplane, according to case 200 of the "Specifications for the Strength of Airplanes" (three-point landing, landing with large angle of attack). For simulation of the lift force which is to precisely balance this weight (see BVF, copy December 1936, Nos. 1213 and 1223), buffers were used. By preliminary tests, the buffer pressure was fixed so that the energy balance showed only negligibly small errors.[3]

The heights of drop selected were 15, 30, and 45 cm; with the last height, considering the basic values for the impact velocity given in table 6 of No. 1221 of the BVF (edition December 1936), the sinking velocity of the airplane model W 34 was slightly exceeded and that of the airplane model Ar 81 approximately reached.

The test setup for the drop-hammer tests is represented in figure 5. The shock strut surrounded by a thermally insulated cooling jacket is clamped in the drop hammer; ahead of the shock strut a landing wheel with tire 815 × 290 is connected, guided within the drop hammer in the direction of fall; the tire pressure was maintained constant at 2.75 kg/cm^2 in all tests.

Before each test, cooling fluid (alcohol and dry ice) were poured into the cooling jacket; by continuous addition of small pieces of dry ice, the coolant was kept at a certain temperature until the oil in the interior of the shock strut had reached the desired temperature. The necessary cooling time was, for -40° C, approximately 1-1/2 hours. Before each drop-hammer test, the cooling fluid had to be drained out of the cooling jacket in order to avoid its squirting out. After each drop-hammer test, before the cooling fluid was poured in again, the shock strut had to be warmed in order to let the viscous oil adhering to the interior walls of the shock strut flow back into the oil chamber of the shock strut.

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[3]The errors are caused by the fact that the drop-hammer weight balance shows a certain friction; therefore, the drop-hammer weight balancing force indicated without this friction in the numerical tables is somewhat smaller than the drop-hammer weight.

Figure 5 shows, beside the measuring devices of the drop hammer and the buffers, also the apparatus used for measuring, before every test, the air pressure in shock strut and tire, and the temperature of the cooling fluid and of the oil in the shock strut; for the measurement of temperature iron-constantan thermocouples were employed, the so-called "cold soldering point" of which was kept in boiling water at exactly $+100^\circ$ C; for reading off two millivoltmeters were used together with which the thermocouples had been calibrated in $^\circ$C.

2. Friction Tests in the Compression Press

As mentioned before, friction tests in the compression press were carried out for determination of the lubricity of the different oils under investigation. First, friction tests were performed with vertical loading on a vertical VDM shock strut model 400 at low temperatures in order to find out whether the frictional conditions at temperatures down to -40° C change essentially compared to those prevailing at room temperature. Figure 6 represents the installation of the shock strut into a 10 t-press of the DVL. The pressure and temperature measuring apparatus are the same as those described above in the drop-hammer tests.

Since, with this test arrangement, no essential difference in the lubricity of the various oils could be determined, and since also at temperatures between $+20^\circ$ and -40° C, the magnitude of friction in the shock strut did not change significantly, another test arrangement was chosen which is schematically represented in figure 7.

A cantilevered VDM shock strut model 700 was swivel supported with its upper ball joint in the crosshead of the 100 t-press of the DVL. The piston rod of the shock strut was bolted to a collar so as to be rigid in bending; the latter could be shifted on a shaft of large dimensions; the one offset end of the shaft was swivel supported on the lifting table of the press by means of a steel ball whereas the other end of the shaft was provided with a cap nut. After taking off the cap nut, the spacer rings placed on the shaft could be taken off and put on again in changed sequence to the right or left of the collar of the shock strut whereby the angle at which the shock strut was loaded could be varied from approximately 2° in increments of 2° up to a maximum angle of $27^\circ 30'$ with respect to the normal. The various inclinations of the shock strut attained by shifting of the spacer rings could be determined with sufficient accuracy by means of a protractor level provided with a scale and with a spirit level.

For each of the shock strut oils, we measured beside the air pressure and the respective inclination of the shock strut that force which was required for just barely setting the piston rod in motion against the cylinder. On the balance of the 100 t-press, the instant of the first movement of the piston rod could be observed due to the fact that the force immediately decreased slightly at transition from static to sliding friction. The first movement of the piston rod was immediately noticeable also on the precision manometer which was permanently connected with the air space of the shock strut, due to a clearly recognizable increase in pressure. The initial friction forces measured for each of the oils mentioned at the various shock-strut inclinations give a good indication of the lubricity of these oils; naturally, the values measured were only comparative values since with another type of shock strut construction, other values would result.

C. TEST PERFORMANCE AND TEST RESULTS

1. Cold Tests in the Drop Hammer

a. Preamble.- Originally it had been planned to investigate every type of oil in each of the shock strut models in order to observe the behavior of the three different oils in flowing through the different throttling organs of the three shock struts; furthermore, investigation of six temperature steps between +20° and -40° C in each of these nine test series had been provided for in order to determine at what temperature the effect of cold begins to become clearly noticeable. For each temperature step, drop-hammer tests with at least three different heights of drop must be carried out for determination of the influence of velocity.

The tests of the first test series which was carried out with six temperature steps and three heights of drop each showed that four temperature steps with three heights of drop each in every test series gave sufficient information of the effects of temperature and velocity on the oleo shock struts and the oils. Since it was further found in the first four test series that the different types of shock strut construction investigated did not show any essential differences for the same airplane model when the same oil was used, the number of test series was limited to 7. Although the number of single tests was reduced, due to these eliminations, to about one half of that originally planned, there were still about 90 individual drop-hammer tests to be performed and evaluated.

In order to avoid more variables, the following values were kept constant in the drop-hammer tests: The internal pressure of the associated pneumatic tire; the initial pressure of the compressed air of the oleo shock struts at the respective test temperature.

By this means an operating condition was simulated as may occur for instance in a longer period of cold or else after high-altitude flights. For the first case, it is presupposed that the shock strut (especially its oil chamber) has assumed a degree of cold corresponding to the low external temperature, but that the required internal pressure of the tire and of the air shock strut has been exactly maintained. For the second case, one could arrive at the conditions prevailing at the test, for instance, by starting out with the assumption that at the take-off the required tire pressure corresponding to the temperature prevailing on the ground existed, whereas the air pressure of the shock strut was somewhat higher than necessary; in high-altitude flights, the shock struts will probably cool off more rapidly than the tires; also, in case of wheels and fixed landing gear, the sun radiation could have the effect that when landing the tires have the same temperature as at the take-off, whereas the shock struts show a lower temperature in which case the air pressure of the shock struts could correspond exactly to the required air pressure.

Whereas, in the tests with oleo air shock struts, the entire cylinder and part of the piston rod are cooled, in tests with the oleo rubber shock strut first only the oil chamber lying at the bottom is cooled (for comparison with the tests on oleo air shock struts) with the rubber shock rings kept as far as possible at room temperature; thereby, the influence of the throttling organ of the other shock struts may be compared under otherwise approximately equal initial conditions. Furthermore, supplementary tests were carried out with the oleo rubber shock strut where the entire shock strut (oil chamber and rubber shock absorber) were cooled to the same degree; this condition largely corresponds to the actual conditions in landing with oleo rubber shock struts at low temperatures so that these supplementary tests may serve for estimation down to what temperatures oleo rubber shock struts may be used without danger.

Regarding the graphs discussed below, it should be remarked, in general, that the strut deflections and forces of the entire landing-gear half and of the shock strut alone were plotted against time by the measuring apparatus on the DVL drop hammer. Whereas the path-time and force-time curves of the total springing are used only for determination of the energy balance and for spot-check control of the shock-strut values, the path-time and force-time curves of the shock strut alone were evaluated, plotted as force-path-curves, and evaluated by planimeter.

The characteristic values of the shock strut (maximum force, maximum strut deflection, energy absorption, damping, and planimetric ratio (shock-strut effectiveness)[4] were determined and plotted as functions of the drop of height; in another graphic representation, the characteristic values were plotted as functions of the temperature.

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[4]The definition of the maximum force P, of the maximum strut deflection f, of the energy absorption A, of the damping D, and of the planimetric ratio (shock-strut effectiveness) η may be seen from figure 33.

b. VDM oleo air shock strut (model 400).- First, the three different oils were investigated one after the other in the VDM oleo air shock strut; the prescribed oil quantity was poured in and checked before each test by means of the built in oil-level gage. For maintenance of the required initial air pressure of 42 kg/cm^2, in tests at room temperature, the compressed air was replenished until the air pressure in the shock strut remained constant when the test temperature was maintained.

Since at the start of the tests the influence of the temperature reduction on the springing and damping properties of the landing-gear half was not known, the following temperature steps were selected in the first test series:

$$+18^\circ,\ \pm 0^\circ,\ -10^\circ,\ -20^\circ,\ -30^\circ,\ -40^\circ\ C$$

Since in the evaluation of this test series the curves of the characteristic values plotted against the temperature were found to be smooth curves, the following temperature steps were selected for the following test series:

$$+18^\circ,\ \pm 0^\circ,\ -20^\circ,\ -40^\circ\ C$$

(α) I. Test series (VDM shock strut and AB 11 oil):

In figure 8, the force-path curves of the shock strut for the three drops of height investigated - of 15, 30, and 45 cm - and for temperatures of $+18^\circ$, $\pm 0^\circ$, -10°, and -30° C are plotted; in figure 9, the corresponding curves for temperatures of -20° and -40° C are represented (compare the numerical tables 1 and 2).

If one compares the force-path curves obtained for a certain height of drop under the effect of various temperatures, one recognizes that at lower temperatures the deflection of the shock struts decreases and the maximum strut force increases; in figure 8, this tendency is not very pronounced and, accordingly, the energy absorptions do not deviate very much from one another; in figure 9, however, one can already see very considerable differences; the energy absorption of the shock strut is greatly reduced with decreasing temperature.

In figure 10, the data ascertained from the force-path curves (figs. 8 and 9) are plotted against the temperature; therein the influence of the decreasing temperature is shown to be most pronounced in the increase of the maximum force and of the damping and - hardly less clearly - in the decrease of the energy absorption and strut deflection, whereas the planimetric ratio (shock-strut effectiveness) remains approximately constant. Down to a temperature of -10°, one cannot notice for hardly any curve an essential change in direction.

In figures 11 and 12, the same data are plotted once more against the height of drop. In figure 12, especially the variation of the damping curve is striking since with decreasing temperature the damping increases strongly only in case of slight impact velocities.

(β) II. Test series (VDM shock strut and S 2069 oil):

In numerical table 3 all tests with the VDM shock strut and the vacuum oil S 2069 have been compiled. In figure 13, the force-path curves for three different impact velocities and four temperature steps are plotted. The force-path curves show that for large heights of drop, the energy absorption does not decrease with the temperature so rapidly as for small heights of drop. The same tendency is evident from figure 14 where the characteristic values are plotted against the temperature. Furthermore, it is conspicuous that the curves of the maximum forces greatly deviate even at $\pm 0^{\circ}$.

(γ) III. Test series (VDM shock strut and DMB oil):

Numerical table 4 shows a compilation of the tests carried out with the VDM shock strut and the DMB hydraulic fluid. The force-path curves for three heights of drop and four temperature steps presented in figure 15 show clearly that no essential increase of force and no considerable decrease of energy absorption is connected with decreasing temperature. The same phenomenon can be seen clearly from figure 16 where the characteristic values are plotted against the temperature. The very flat slope of the force curves and the slight reduction of energy absorption and strut deflection with decreasing temperature is noteworthy.

(δ) Summary of the first three test series:

In figures 17 to 19 we have compiled once more force-path curves and characteristic values of those tests that had been performed with the VDM shock strut and the three different oils for a height of drop of 45 cm and a temperature of -40° C. The force-path curves of figure 17 show clearly that with the oils, Shell AB 11 and Vacuum S 2069, the maximum forces were approximately 1 ton higher than in the case of the DMB hydraulic fluid; with the latter there also resulted the greatest deflection of shock strut in the compression stroke; in the return stroke, it is true, the low lubricity of the DMB oil became noticeable which took effect as an increased packing friction. In figures 18 and 19, the characteristic values of the drop-hammer tests for 45 cm height of drop and -40° C temperature with the VDM shock strut and the three different oils are plotted against the height of drop. From figure 18 one can see that the Shell oil AB 11 shows the most unfavorable values for maximum force, energy absorption, and deflection of the shock strut, that the DMB hydraulic fluid attains the most favorable values, and that the Vacuum oil S 2069 lies between these values but, in general, closer to the AB 11 values.

Likewise, conditions are similar regarding the values for planimetric ratio (shock-strut effectiveness) and damping represented in figure 19.

c. EC oleo-pneumatic shock strut (model 320).- Since it had been found in the first two test series of the drop-hammer tests that the oils AB 11 and S 2069 influence the springing properties of an oleo-pneumatic shock strut similarly throughout, the tests with the EC oleo-pneumatic shock strut were performed only with the Shell AB 11 and Dornier-DMB oils.

(α) IV. Test series (EC shock strut and AB 11 oil):

In numerical table 5, the drop-hammer tests are compiled which were carried out with the EC shock strut and the Shell oil AB 11 for three heights of drop at four temperature stages each.

Figure 20 represents the force-path curves of these 12 individual tests; at temperatures from +18° to -20° C the variations of the force-path curves still show rather close agreement. At -40° C, the shock strut forces increase very markedly with simultaneous reduction of the strut deflection. In figure 21, the characteristic values of this fourth test series are plotted against the temperature. The energy absorption almost does not change at all with the temperature whereas the strut maximum force shows, between ±0° C and -10° C, a pronounced minimum.

(β) V. Test series (EC shock strut and DMB oil):

The force-path curves of the drop-hammer tests with the EC-oleo-pneumatic shock strut and the DMB oil for four temperature stages and three heights of drop each, represented in figures 22 and 23, show - particularly at the temperature of -40° C - a distinct difference compared to the corresponding tests with the EC-shock strut and the Shell oil AB 11; the maximum forces increase slightly with decreasing temperature only for the greatest height of drop; as can be seen from the numerical table 6 and figure 24, where the characteristic values of this test series are plotted against the temperature, the energy absorption is rather independent of the temperature whereas the strut deflection slightly decreases with decreasing temperature.

In the drop-hammer tests with the EC oleo-pneumatic shock strut, a rather large packing friction was observed which manifests itself in the force-path curves (figs. 20, 22, and 23) by the reduced return stroke of the strut. Due to the large packing friction, the influence of the different lubricity of the oils AB 11 and DMB does here not become very noticeable.

d. Arado oleo rubber shock strut (AR 81).- The Arado oleo rubber shock strut was investigated in the drop hammer at low temperatures only with the shock strut oil AB 11. In order to make an evaluation of the influence of the viscosity of the oil on the springing and damping properties of various shock strut models possible, only the oleo chamber of the Arado shock strut was cooled in the sixth test series; however, in order to observe also the effects of low temperatures on the entire oleo rubber shock strut, the entire Arado-shock strut, oleo chamber, and rubber shock absorber were exposed to low temperatures.

(α) VI. Test series (Arado shock strut and AB 11 oil, only oleo chamber of the strut cooled):

In numerical table 7, data have been compiled for those drop-hammer tests with the Arado shock strut where only the oleo chamber of the strut was cooled in four temperature stages from +18° C to -40° C. The force-path curves of this test series are represented in figure 25; one recognizes that the maximum forces at a temperature of -40° C do not lie essentially higher than the maximum forces occuring at the higher temperatures. The characteristic values of this test series, plotted against the temperature in figure 26, show only a slight increase of the maximum forces and of the damping, and a slight decrease of the energy absorptions and deflections of the shock strut with decreasing temperature.

(β) VII. Test series (Arado shock strut and AB-oil, oleo and rubber shock absorber of the strut cooled):

The drop-hammer tests of the seventh test series compiled in numerical table 8 are rendered in figure 27 as force-path curves. Down to a temperature of -20° C, the force-path curves deviate only slightly from those of the sixth test series. At a temperature of -40° C[5], however, the rubber shock absorber seems to bind, the strut deflections become very small, and the maximum forces increase so markedly that the height of drop of 45 cm could no longer be used because the tire would have been endangered. The characteristic values of this test series, plotted against the temperature in figure 28, show almost complete agreement to -10°; starting from -20° C, the increase in force progresses considerably with decreasing temperature while simultaneously strut deflection and energy absorption decrease.

2. Friction Tests in the Compression Press

On all graphs in which the force is plotted against the path, there are always several force-path curves the variation of which seems to indicate an increased friction. With the EC oleo pneumatic shock strut

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[5]The cooling time was for rubber the same as in the case of the spring shock strut about 1-1/2 hours.

which was investigated in factory-new condition, the packing friction is larger than with the VDM oleo pneumatic shock strut which had already been used for testing purposes in flight operation and the packing rings of which therefore had become worked in. Thus, in the EC oleo pneumatic shock strut, other influences which may change the packing friction do not become as strongly noticeable as in the case of the VDM oleo pneumatic shock strut. In the case of the Arado oleo rubber shock strut, the steep slope of the returning branch of the force-path curves is due not so much to an increased friction as to the lacking initial pressure.

For both oleo pneumatic shock struts, however, the force-path curves do not show unequivocally whether the influence of the low temperatures or that of the different oil types has a stronger effect on the friction; therefore, two test series were set up in order to determine separately the influence of the temperature and of the oil type on the friction.

For the first of these test series, the test arrangement represented in figure 6 was selected for ascertaining the influence of the temperature on the magnitude of the friction. The first tests which were carried out with a VDM oleo pneumatic shock strut model 400, under compression stress only, and with AB-11 oil, did not show a considerable change in friction at temperatures down to -40° C. Since the Shell oil AB-11, according to the previous test results, had shown in every respect the greatest variation with temperature in the investigated range, in this test series no further tests with other low temperature oils were performed since no different results would have been expected.

The second of these test series was carried out with the loading device represented in figure 7 in order to determine the influence of the lubricity of the different oil types on the magnitude of the friction at room temperature (20° to 22° C). The static-loading tests performed with a cantilevered VDM oleo pneumatic shock strut (model 700) under compression and bending stress had the following results:

For all oils and oil mixtures, the force required for overcoming the initial pressure and the static friction increased with increasing inclination angle of the shock strut.

The internal air pressure of the shock strut was continuously checked and kept constant by means of a precision manometer so that the initial pressure of the shock strut also was always the same. Thus, in figures 29 and 30 the measured force was plotted on the ordinate as a multiple S of the constant initial pressure; on the abscissa, the inclination of the shock strut toward the perpendicular was plotted in degrees.

In figure 29, the friction curves of the three shock strut oils investigated in the drop-hammer tests are represented as a function of the inclination of the shock strut. For the inclination 0° the frictional forces of the three oils still show agreement to some extent; however, with increasing inclination of the shock struts, the oils differ considerably.

The Shell oil AB-11 shows in the lower branch of its friction curve (to about 15°) a considerably flatter . . .[6]

Since for the investigated oils a certain conformity was found between the pour point of an oil and its behavior in the shock strut at low temperatures, it appears feasible to draw conclusions from their pour point to their behavior in the shock strut at low temperatures also for the oil mixtures not investigated in the drop hammer. Accordingly, mixture of the oils DMB and V 50806 in the ratio 1:1 is to be regarded as most favorable since there the pour point lies even lower than -73° C and the lubricity seems sufficient, on the basis of the friction tests.

D. INFLUENCE OF THE OIL VISCOSITY ON THE SPRINGING PROPERTIES OF SHOCK STRUTS

The tests have shown that at temperatures above 0° C, it makes no difference for the springing properties which one of the oils investigated is used. Only at temperatures of -20° C and below do essential differences in the springing properties appear with the use of different oils, that is, the oil viscosity plays a role only when it exceeds the order of magnitude of 100 Centistoke (10 to 20 Engler degrees).

As the curves of figure 4 show, the different oils are, in the temperature range considered, of the same viscosity when the temperature of the DMB oil is about 32° C lower and that of the Vacuum S 2069 oil about 8° C lower than the temperature of the Shell AB 11 oil. If the springing properties of the struts were influenced solely by the viscosity and not also by other properties of the oils, as well as by the temperature effect (although this effect is slight) on the oil-passage apertures and on the air compression, conformity would have to exist between the curves represented in figures 10, 14, and 16 (for the VDM shock strut) and in figures 21 and 24 (for the EC shock strut) as to the strut deflection f, the strut force P, and the energy absorption A for various oils, if f, P, and A are represented as functions of the viscosity, or (which amounts to the same thing) if - in order to enable immediate use of the graphical

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[6]NACA editor's note: In the original German paper used for this translation, the continuity at this point is confused as material from the preceding page is repeated and the material that obviously should follow is omitted. However, the value of the paper does not appear greatly harmed by this omission.

representations, figures 10, 14, 16, 21, and 24 indicated above - f, P, and A are represented as functions of the temperature t, however, in such a manner that the abscissas t for the various oils are shifted with respect to one another so that every point of the abscissa corresponds to the same degree of viscosity.

However, therein the curves for the various oils show differences which prove that aside from the viscosity, other differences take effect as well, in such a manner that the viscosity, if its influence is considered all by itself, does not find expression to the full extent. If one makes, therefore, the corresponding plotting (as was done in fig. 31 (for the VDM strut) and 32 (for the EC strut)) as a function of the temperature, for instance, in such a manner that on the abscissa for the various oils the temperatures differ only by half the value of the temperature difference at which equal viscosity exists (if one therefore plots on the abscissa, a temperature difference of 16° between DMB oil and Shell AB oil, and of 4° between Vacuum S 2069 oil and Shell AB-11 oil), there results rather good agreement in the fundamental shape of the curves for f, P, and A, particularly for the oils DMB and AB-11 which differ greatly in viscosity. This result, found for the present case by a rather arbitrarily simplified method, may, of course, not be regarded as generally valid.

It is not possible to derive from the tests made so far an unequivocal relation between the lubricity of the oils (ascertained by static tests) on one hand and the maximum strut deflection, strut force, and energy absorption on the other. The smaller the lubricity, the less distance the shock strut returns in springing back immediately after the impact to its initial position.

A general clarification of the influence of the oil properties on the springing properties of shock struts would require more extensive fundamental investigations.

E. SUMMARY

Drop-hammer tests with various shock strut models and various shock strut oils were carried out at low temperatures; the purpose of the tests was to determine at what temperatures operation is impaired. The shock strut models investigated which were designed for about equal static wheel loadings and impact velocities did not show significant differences as to maximum forces and energy absorptions attained if the same shock-strut oils were used. Only in the case of one oleo rubber shock strut it was found, at a temperature of -40° C that, although the operation of the oleo chamber was not yet impaired, the rubber shock rings were practically ineffective.

Regarding the shock-strut oils investigated, it was established that the oils so far chiefly used as shock-strut oils, namely "Shell AB 11" and "Vacuum S 2069" (pour point at -60° C to -65° C) caused at temperatures below -20° C, a considerably larger increase in force than the "Dornier-hydraulic fluid (DMB oil)" (pour point below -73° C).

It was possible to prove - by static loading tests with a cantilevered, obliquely mounted oleo-shock strut the inclination of which was varied from 0° to 27°30' in the compression press - that among the oils investigated in the drop hammer, the DMB oil showed the least lubricity, the S 2069 Vacuum oil an only slightly better one, the AB-11 Shell oil the best one. The DMB oil also had caused increased packing-friction in the drop-hammer tests.

Furthermore, it was established with the same test arrangement that, by mixing the cold-resistant DMB oil with a special Shell oil V 50806 (which had been made very fatty) in the ratio 1:1, the lubricity of the mixture could be greatly improved; the pour point of this mixture was even lower than -73° C. The mixture thus obtained shows about the same lubricity as the Shell AB-11 oil and also shows a resistance to low temperatures which does not seem inferior to that to the DMB oil.

The usefulness of such a cold-resistant oil mixture would, of course, still have to be examined with regard to the wear on the packing rings and with regard to corrosion.

Translated by Mary L. Mahler
National Advisory Committee
for Aeronautics

TABLE 1 - DROP-HAMMER TESTS IN THE DVL THREE-TON DROP HAMMER

DVL Institute for Strength	Account Cf319/1 Tests made: Kieback/Mucha Checked: Kranz	Data for shock strut Manufacturer VDM	Model 400 Oil type AB-11 Shell Oil quantity 490 cm^3	Construction type oleo-pneumatic Airplane model Ju W 33 Inflation pressure 42 atm
		Drop-hammer weight 1306 kg Drop-hammer weight balance 1180 kg (100 kg = 1 atm) Transmission $\frac{f\ wheel}{f\ strut}$ 1:1 constant	Tire size 815 × 290 Internal pressure 2.75 atm Static wheel load kg	Remarks Shock-strut investigations at low temperatures

Test No.	Free height of drop, h, cm	Values obtained for - Deflection: f total, cm	f strut, cm	Maximum force: P total, kg	P strut, kg	Impact, $\frac{P\ total}{G/2\ Airplane}$, e	Energy - Absorption: A total, mkg	A strut, mkg	Return: A' total, mkg	A' strut, mkg	Damping: D total, percent	D strut, percent	Planimetric ratio (shock-strut effectiveness): η total	η strut, percent	Remarks: Tests at a strut temperature of -
2018	15	13.5	7.6	2414	2160			150.7		66.2		56		91.5	
2019	30	19.8	12.9	2710	2620			312.4		87.4		72		92.3	+18°
2020	45	24.3	15.9	3357	3320			458		71.		84.5		87	
2003	15	12.8	7	2600	2260			144.2		64.8		55		91.2	
2004	30	19.8	12.3	2730	2730			306.2		79.2		74.2		92.6	±0°
2005_b	45	23.5	15.1	3430	3430			468.		71.5		84.8		90.5	
2006	15	12.8	6.7	2630	2370			144.4		60.9		57.8		90.4	
2007	30	18.6	11.1	3115	2980			304.4		64.4		78.8		90.1	-10°
2008	45	22.6	13.9	3640	3540			445.		58.		87.1		91.	
2009	15	12.7	5.6	2810	2580			131.8		38.3		71.		91.2	
2010	30	18	10.2	3430	3180			294.		56.		81.		90.4	-20°
2011	45	22.1	72.9	3830	3660			432.8		46.		89.5		91.9	

TABLE 2 - DROP-HAMMER TESTS IN THE DVL THREE-TON DROP HAMMER

DVL Institute for Strength	Account Cf319/1 Tests made: Kieback/Mucha Checked: Kranz	Data for shock strut Manufacturer VDM Model 400 Oil type AB-11 Shell Oil quantity 490 cm^3 Construction type oleo-pneumatic Airplane model Ju W 33 Inflation pressure atm
		Drop-hammer weight 1306 kg Drop-hammer weight balance 1180 kg 100 kg = 1 atm) Transmission $\frac{f\ wheel}{f\ strut}$ 1:1 constant Tire size 815 × 290 Internal pressure 2.75 atm Static wheel load kg Remarks: Shock-strut investigations at low temperatures

Test No.	Free height of drop, h, cm	Values obtained for - Deflection: f total, cm	f strut, cm	Maximum force: P total, kg	P strut, kg	Impact, $\frac{P\ total}{G/2\ Airplane}$, e	Energy - Absorption: A total, mkg	A strut, mkg	Return: A' total, mkg	A' strut, mkg	Damping: D total, percent	D strut, percent	Planimetric ratio (shock-strut effectiveness): η total	η strut, percent	Remarks: Tests at a strut temperature of -
2012	15	12	3.8	3180	2980			104.2		17.2		83.3		92.1	-30°
2013	30	17.3	8.3	3840	3550			268.6		34.6		87		90.6	
2014	45	21	11.4	4280	3940			414.2		47		88.8		92.3	
2015	15	11.5	7.25	3485	3400			38.8		1		97.5		92.8	-40°
2016	30	16	5.2	4475	4200			201.2		2.2		99		92	
2017	45	19.5	8.2	5140	4720			359.8		11		94.4		92.5	

TABLE 3 - DROP-HAMMER TESTS IN THE DVL THREE-TON DROP HAMMER

DVL Institute for Strength	Account Cf319/1 Tests made: Kieback/Mucha Checked: Kranz	Data for shock strut: Manufacturer VDM; Model 400; Oil type Vacuum S 2069; Oil quantity 490 cm3; Construction type oleo-pneumatic; Airplane model Ju W 33; Inflation pressure 42 atm
		Drop-hammer weight 1306 kg; Drop-hammer weight balance (100 kg = 1 atm) 1200 kg; Transmission $\frac{f\ wheel}{f\ strut}$ 1:1 constant; Tire size 815 x 290; Internal pressure 2.75 atm; Static wheel load kg; Remarks: Shock-strut investigations at low temperatures

Test No.	Free height of drop, h, cm	Values obtained for - Deflection: f total, cm	f strut, cm	Maximum force: P total, kg	P strut, kg	Impact, $\frac{P\ total}{G/2\ Airplane}$, e	Energy Absorption: A total, mkg	A strut, mkg	Energy Return: A' total, mkg	A' strut, mkg	Damping: D total, percent	D strut, percent	Planimetric ratio (shock-strut effectiveness): η total	η strut, percent	Remarks: Tests at a strut temperature of -
2021	15	13.6	7.8	2380	2120		203.6	156		69.7		55.3		94.3	+18°
2022	30	20	12.8	2750	2670			315		71.2		77.4		92.3	+18°
2023	45	24.2	75.9	3330	3300		591.2	455		65.5		85.6		86.7	+18°
2024	15	13.3	7.1	2430	2170		203	144.5		59		58.2		93.7	±0°
2025	30	19.4	12.4	2780	2760			310.6		70.6		77.4		91	±0°
2026	45	24	15.5	3360	3310		588.8	455		68.5		85		88.6	±0°
2027	15	12.4	5.8	2775	2480			132.8		38.5		71.1		92.2	-20°
2028	30	18.2	10.5	3285	3130			300.5		47.5		84.1		91.6	-20°
2029	45	22.2	13.2	3715	3680			440		45		89.8		90.5	-20°
2030	15	11.6	1.4	3540	3380			42.5		0.6		98.6		90	-40°
2031	30	16.2	6.1	4460	4070			234		15		93.6		94	-40°
2032	45	20.2	10.3	5100	4670			434		58		86.6		90.2	-40°

TABLE 4 - DROP-HAMMER TESTS IN THE DVL THREE-TON DROP HAMMER

DVL Institute for Strength	Account Cf319/1 Tests made: Kieback/Mucha Checked: Kranz	Data for shock strut Manufacturer VDM	Model 400 Oil type DMB blue Oil quantity 490 cm3	Construction type oleo-pneumatic Airplane model Ju W 33 Inflation pressure 42 atm
		Drop-hammer weight 1306 kg Drop-hammer weight balance 1220 kg (100 kg = 1 atm) Transmission $\frac{f\ wheel}{f\ strut}$ 1:1 constant	Tire size 815 × 290 Internal pressure 2.75 atm Static wheel load kg	Remarks Shock-strut investigations at low temperatures

Test No.	Free height of drop, h, cm	Values obtained for - Deflection: f total, cm	f strut, cm	Maximum force: P total, kg	P strut, kg	Impact, $\frac{P\ total}{G/2\ Airplane}$, e	Energy - Absorption: A total, mkg	A strut, mkg	Return: A' total, mkg	A' strut, mkg	Damping: D total, percent	D strut, percent	Planimetric ratio (shock-strut effectiveness): η total	η strut, percent	Remarks: Tests at a strut temperature of -
2033	15	13.6	7.5	2340	2040			143		61		57.3		93.4	+18°
2034	30	19.9	12.8	2680	2600		398	303.2		76.6		74.9		91	
2035	45	24.4	16.1	3240	3200			453		68		85		88	
2036	15	13.6	7.7	2360	2100		203.8	148.3		63.8		56.9		91.6	±0°
2037	30	19.8	12.8	2730	2640			308.8		73.6		76.1		91.4	
2038	45	24.3	16	3300	3280		583.2	455.6		63.6		86		86.7	
2039	15	12.9	6.7	2580	2310			143.5		47.2		67.1		92.7	-20°
2040	30	18.9	11.4	2980	2860			297		53.4		82		91.1	
2041	45	23.3	14.6	3430	3400			448		56		87.6		90.3	
2042	15	12.3	5.3	2820	2570		202.6	126.6		22.2		82.5		92.9	-40°
2043	30	18	9.7	3370	3200			284.4		27.2		90.4		91.6	
2044	45	22.2	13.2	3700	3640		583	426.8		47.2		89		88.8	

TABLE 5 - DROP-HAMMER TESTS IN THE DVL THREE-TON DROP HAMMER

DVL Institute for Strength	Account Cf319/1 Tests made: Kieback/Mucha Checked: Kranz	Data for shock strut Manufacturer EC Cannstatt	Model 320 Oil type AB-11 Shell Oil quantity 980 cm^3	Construction type oleo-pneumatic Airplane model Ju W 33 Inflation pressure 36.4 atm
		Drop-hammer weight 1306 kg Drop-hammer weight balance 1220 kg (100 kg = 1 atm) Transmission $\frac{f\ \text{wheel}}{f\ \text{strut}}$ 1:1 constant	Tire size 815 × 290 Internal pressure 2.75 atm Static wheel load kg	Remarks Shock-strut investigations at low temperatures

Test No.	Free height of drop, h, cm	Values obtained for - Deflection		Maximum force		Impact,	Energy Absorption		Return		Damping		Planimetric ratio (shock-strut effectiveness)		Remarks
		f total, cm	f strut, cm	P total, kg	P strut, kg	$\frac{P\ \text{total}}{G/2\ \text{Airplane}}$, e	A total, mkg	A strut, mkg	A' total, mkg	A' strut, mkg	D total, percent	D strut, percent	η total	η strut, percent	Tests at a strut temperature of -
2065	15	14.9	8.1	2170	2120			138.7		28.5		79.5		81.0	
2066	30	21.5	12.1	2930	2900			255.0		40.0		84.3		72.7	+18°
2067	45	26.6	15.1	3780	3660			371.0		60.0		84.0		67.1	
2068	15	14	7.3	2400	1890			132.2		19.3		85.3		95.8	
2069	30	21	11.8	2860	2800			261.3		30.4		88.5		79.0	±0°
2070	45	26	14.9	3570	3550			383.5		44.5		88.5		72.5	
2071	15	13.3	6.7	2600	2110			132.8		12.5		90.8		94.0	
2072	30	20	10.9	2930	2860			253.0		15.5		94.0		81.2	-20°
2073	45	24.8	14.1	3600	3580			371.0		22.5		94.0		73.2	
2074	15	11.9	4	2970	2680			105.0		3.0		97.2		98.0	
2075	30	17.8	8.1	3580	3360			252.5		4.5		98.2		92.8	-40°
2076	45	22.1	10.4	4400	4360			374.0		5.7		98.6		82.5	

TABLE 6 - DROP-HAMMER TESTS IN THE DVL THREE-TON DROP HAMMER

DVL Institute for Strength	Account Cf319/1 Tests made: Kieback/Mucha Checked: Kranz	Data for shock strut Manufacturer EC Cannstatt	Model 320 Oil type DMB blue Oil quantity 980 cm³	Construction type oleo-pneumatic Airplane model Ju W 33 Inflation pressure 36.4 atm
		Drop-hammer weight 1306 kg Drop-hammer weight balance 1220 kg (100 kg = 1 atm) Transmission $\frac{f\ wheel}{f\ strut}$ 1:1 constant	Tire size 815 × 290 Internal pressure 2.75 atm Static wheel load kg	Remarks Shock-strut investigations at low temperatures

Test No.	Free height of drop, h, cm	Values obtained for - Deflection: f total, cm	f strut, cm	Maximum force: P total, kg	P strut, kg	Impact, $\frac{P\ total}{G/2\ Airplane}$, e	Energy - Absorption: A total, mkg	A strut, mkg	Return: A' total, mkg	A' strut, mkg	Damping: D total, percent	D strut, percent	Planimetric ratio (shock-strut effectiveness: η total	η strut, percent	Remarks: Tests at a strut temperature of -
2077	15	14.4	7.7	2215	1960			130.7		34		74		86.5	+18°
2078	30	21.1	11.8	2930	2900			250.5		46.7		81.3		73.3	
2079	45	26.3	15.5	3510	3480			390.8		74		81		72.4	
2080	15	13.8	7	2400	2010			127.1		25.2		80.2		90.3	±0°
2081	30	21	11.8	2890	2860			244.5		44		82		72.5	
2082	45	26.1	15.4	3500	3460			386.5		68.3		82		72.5	
2083	15	13.6	6.8	2380	2000			125.7		17.3		86.2		92.2	-20°
2084	30	20.5	11.2	2860	2830			246.5		24.2		90.2		77.7	
2085	45	25.8	15.2	3470	3430			368.3		49.5		86.8		70.8	
2086	15	13.2	6.5	2760	2085			132.5		12.5		90.6		97.8	-40°
2087	30	19.7	10.7	3100	2820			255		14.3		94.5		84.5	
2088	45	24.7	13.5	3810	3730			386.8		15.5		96		77	

TABLE 7 - DROP-HAMMER TESTS IN THE DVL THREE-TON DROP HAMMER

DVL Institute for Strength	Account Cf319/1 Tests made: Kieback/Mucha Checked: Kranz	Data for shock strut Manufacturer Arado	Model Ar 81 Oil type AB-11 Shell Oil quantity 310 cm^3	Construction type oil - rubber Airplane model Ar 81 Inflation pressure atm
		Drop-hammer weight 1306 kg Drop-hammer weight balance 1230 kg (100 kg = 1 atm) Transmission $\frac{f\ wheel}{f\ strut}$ 1:1 constant	Tire size 815 × 290 Internal pressure 2.75 atr Static wheel load kg	Remarks Shock-strut investigations at low temperatures

Test No.	Free height of drop, h, cm	Values obtained for - Deflection f total, cm	Deflection f strut, cm	Maximum force P total, kg	Maximum force P strut, kg	Impact $\frac{P\ total}{G/2\ Airplane}$, e	Energy Absorption A total, mkg	Absorption A strut, mkg	Return A' total, mkg	Return A' strut, mkg	Damping D total, percent	Damping D strut, percent	Planimetric ratio (shock-strut effectiveness) η total	η strut, percent	Remarks Tests at a strut temperature of -
2045	15	14.5	8.2	2200	2130			138		38.5		72.1		79	+18°
2046	30	19.3	10.5	3340	3290			268.5		58.4		78.2		77.8	
2047	45	22.8	11.9	4285	4230			392.5		70		82.2		78	
2048	15	14.4	8.0	2220	2160			136		32.8		76		78.7	±0° (Only the oil cooled)
2049	30	19.1	10.4	3450	3370			276.5		52.5		81		78.8	
2050	45	22.4	11.9	4370	4370			399		60		85		77.8	
2051	15	14.0	7.5	2310	2230			134		23.5		82.5		80	-20° (Only the oil cooled)
2052	30	18.8	10.1	3470	3380			268.2		42		84.4		78.6	
2053	45	22.5	11.7	4450	4380			378		59.5		84.4		73.6	
2054	15	13.6	6.0	2540	2500			115		18.7		83.8		76.7	-40° (Only the oil cooled)
2055	30	18.0	8.6	3640	3570			248		24.8		90		80.8	
2056	45	21.7	10.4	4660	4560			376.5		30		92		79.4	

TABLE 8 - DROP-HAMMER TESTS IN THE DVL THREE-TON DROP HAMMER

DVL Institute for Strength	Account Cf319/1 Tests made: Kieback/Mucha Checked: Kranz	Data for shock strut Manufacturer: Arado	Model: Ar 81 Oil type: AB-11 Shell Oil quantity: 310 cm^3	Construction type: oil - rubber Airplane model: Ar 81 Inflation pressure: atm
		Drop-hammer weight: 1306 kg Drop-hammer weight balance: 1220 kg 100 kg = 1 atm Transmission $\frac{f\ wheel}{f\ strut}$ 1:1 constant	Tire size: 815 × 290 Internal pressure: 2.75 atm Static wheel load: kg	Remarks Shock-strut investigations at low temperatures

Test No.	Free height of drop, h, cm	Values obtained for - Deflection: f total, cm	f strut, cm	Maximum force: P total, kg	P strut, kg	Impact, $\frac{P\ total}{G/2\ Airplane}$, e	Energy - Absorption: A total, mkg	A strut, mkg	Return: A' total mkg	A' strut mkg	Damping: D total, percent	D strut, percent	Planimetric ratio (shock-strut effectiveness): η total	η strut, percent	Remarks: Tests at a strut temperature of -
2045	15	14.5	8.2	2200	2130			138		38.5		72.1		79	+18°
2046	30	19.3	10.5	3340	3290			268.5		58.4		78.2		77.8	+18°
2047	45	22.8	11.9	4285	4230			392.5		70		82.2		78	+18°
2057	15	14.2	8.2	2240	2140			143.2		28.3		80.2		81.7	±0°; Oil and rubber undercooled
2058	30	19.3	10.7	3410	3340			280.5		45		83.9		78.4	±0°; Oil and rubber undercooled
2059	45	22.5	12.1	4450	4310			412		48.3		85.9		78.8	±0°; Oil and rubber undercooled
2060	15	13.8	7.1	2380	2220			129.3		18.7		85.6		81.9	-20°; Oil and rubber undercooled
2061	30	19	9.4	3600	3570			243.4		36.3		85.3		72.5	-20°; Oil and rubber undercooled
2062	45	22.8	11.2	4620	4580			362		55.8		84.6		70.6	-20°; Oil and rubber undercooled
2063	15	12.4	2.3	3300	3160			41.3		2.7		93.4		56.8	-40°; Oil and rubber undercooled
2064	30	16.5	3.4	4710	4570			107.3		11.3		89.5		69.1	-40°; Oil and rubber undercooled

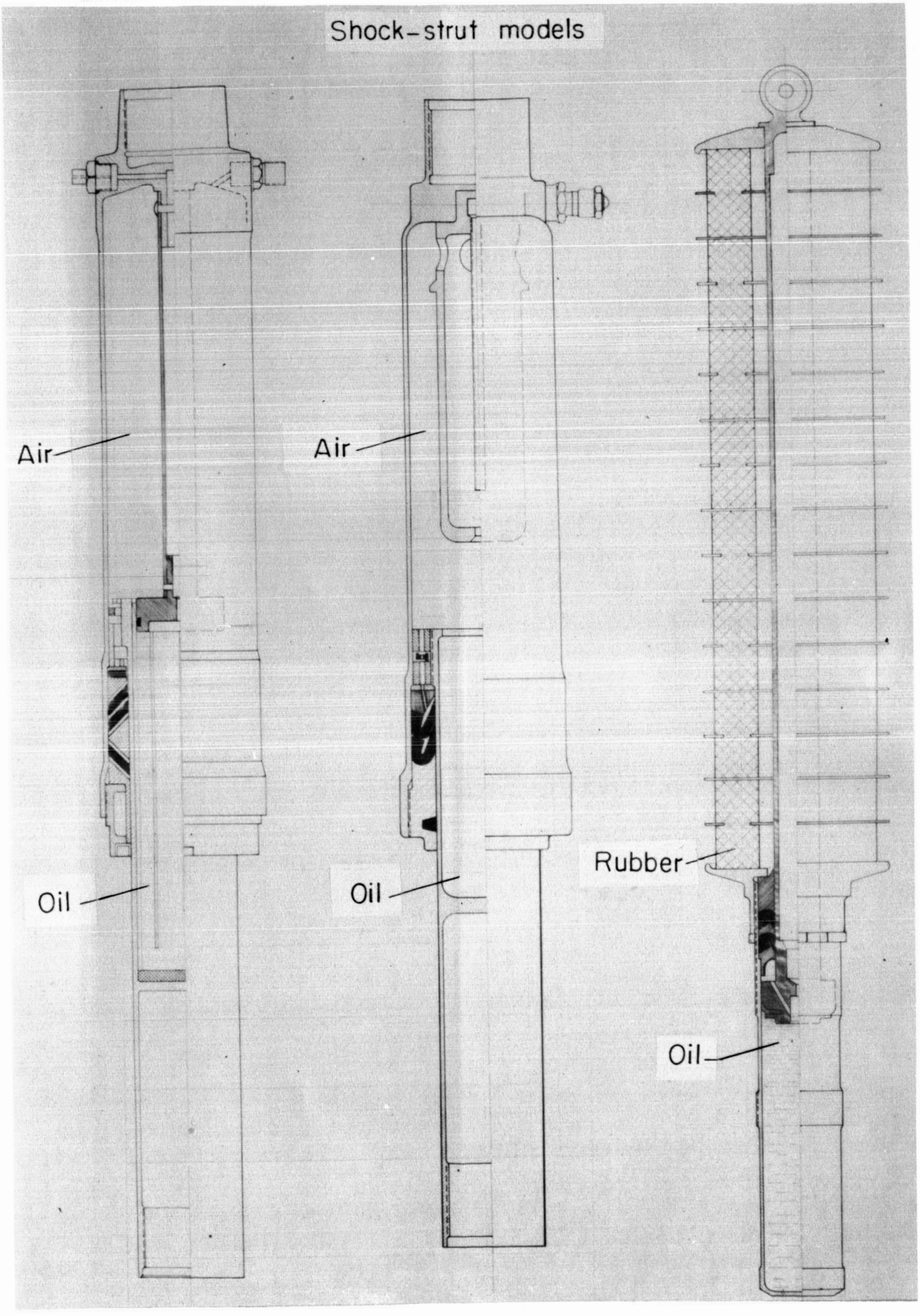


Figure 1.- VDM-400. Figure 2.- EC-320. Figure 3.- Ar. 81.

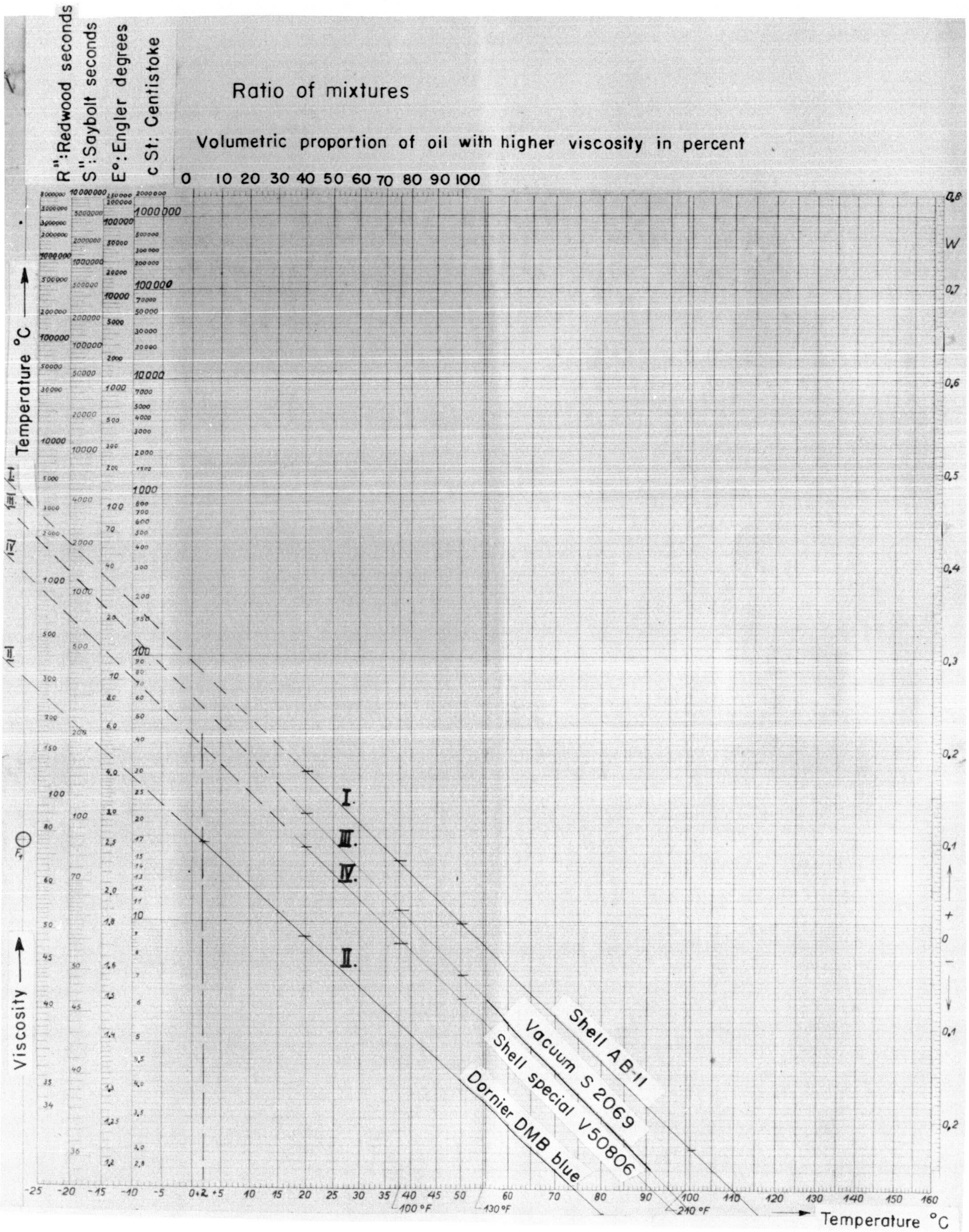


Figure 4.- Viscosity-temperature chart.

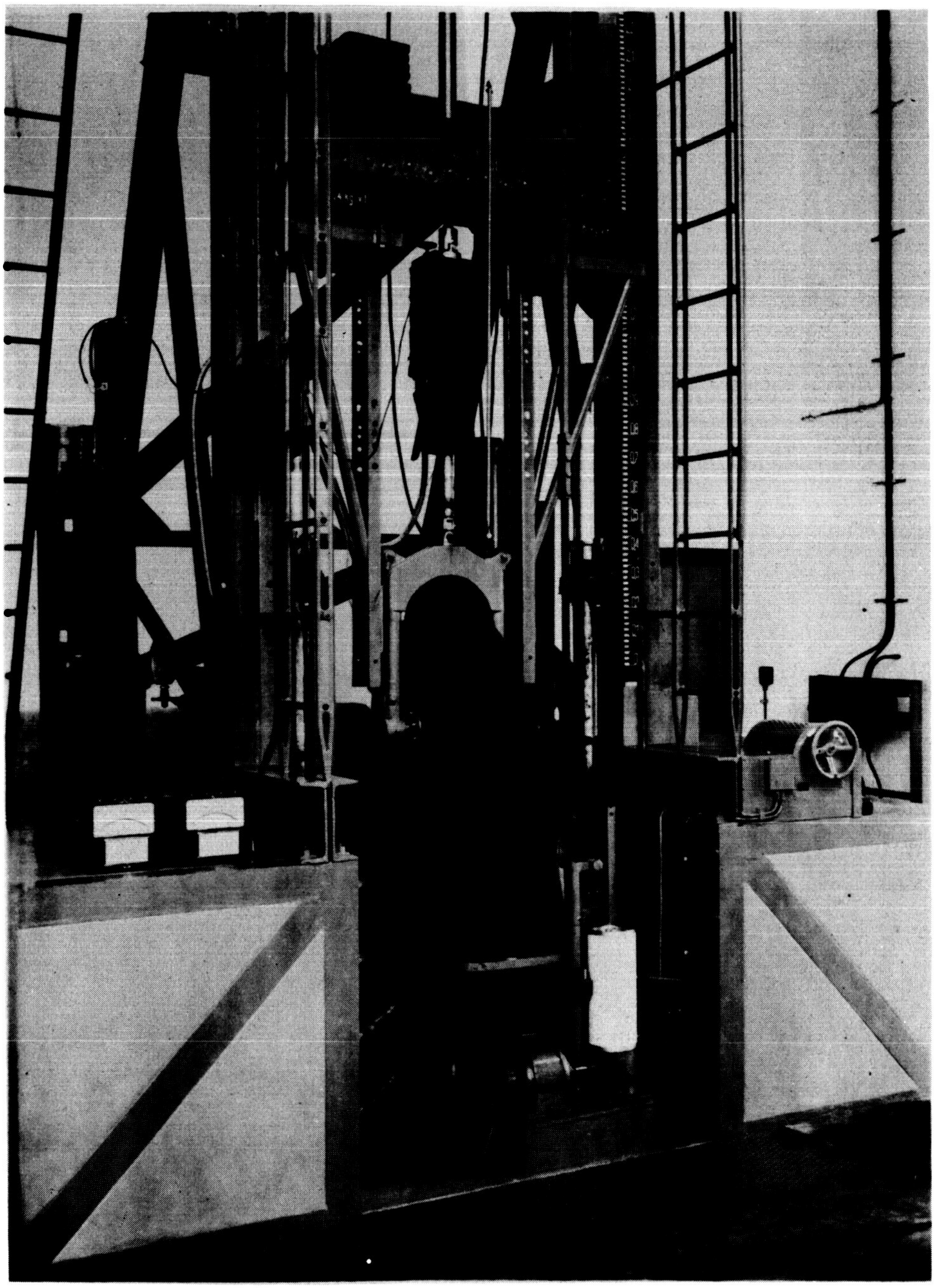


Figure 5.- Cold tests in the three ton drop-hammer test setup with shock strut, cooling, and measuring device.

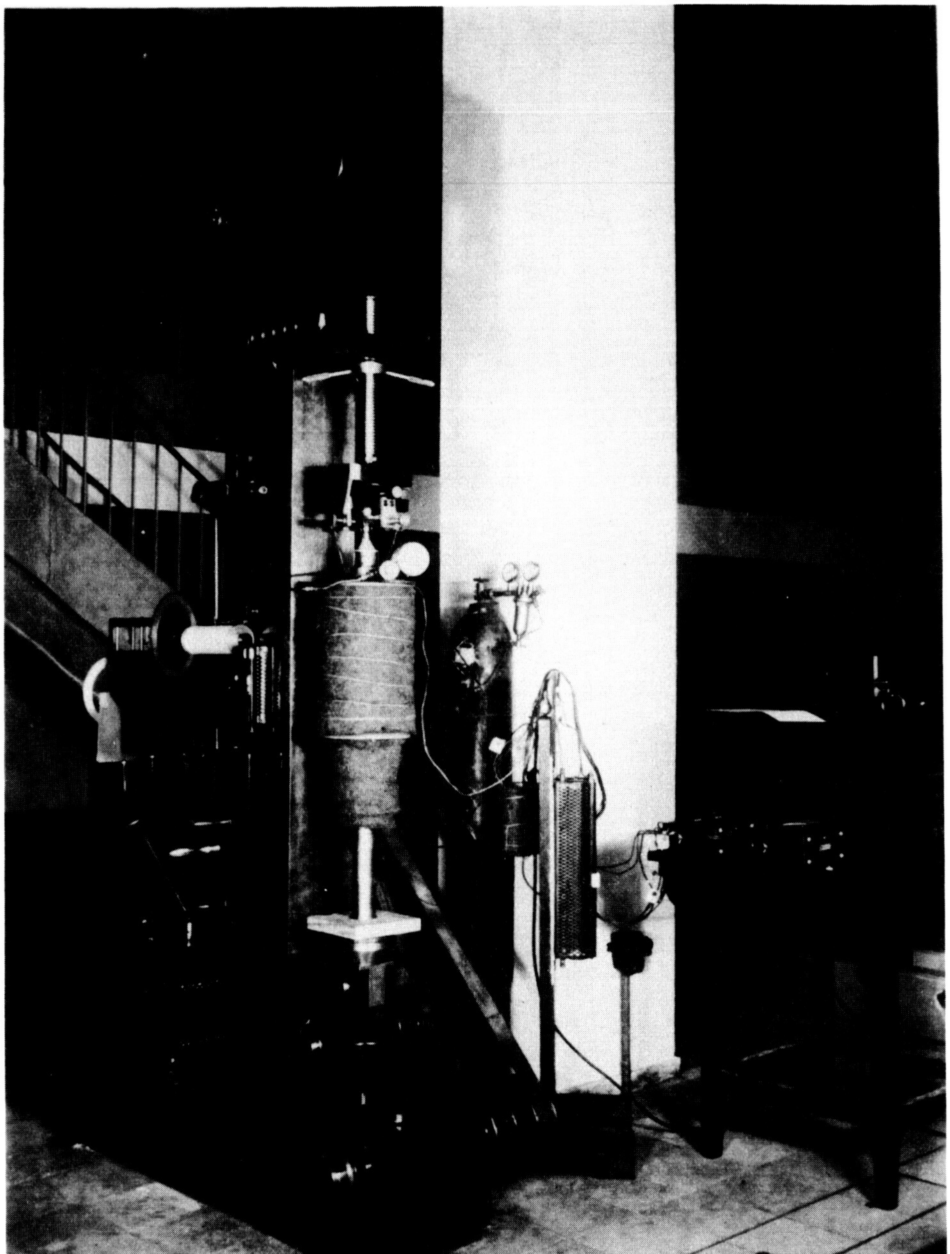


Figure 6.- Friction tests in the 10-ton compression press; vertical loading of the shock strut at low temperatures.

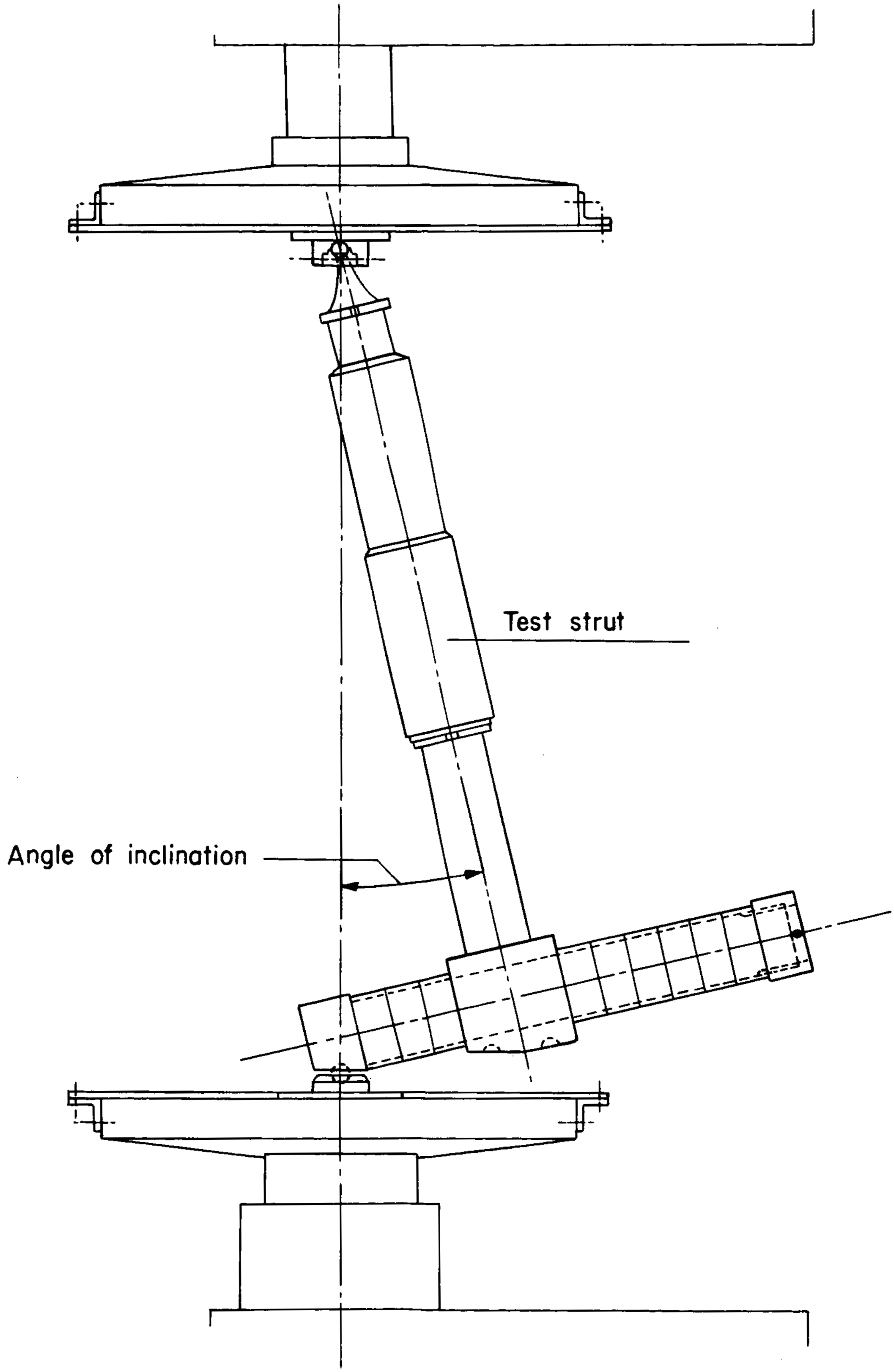
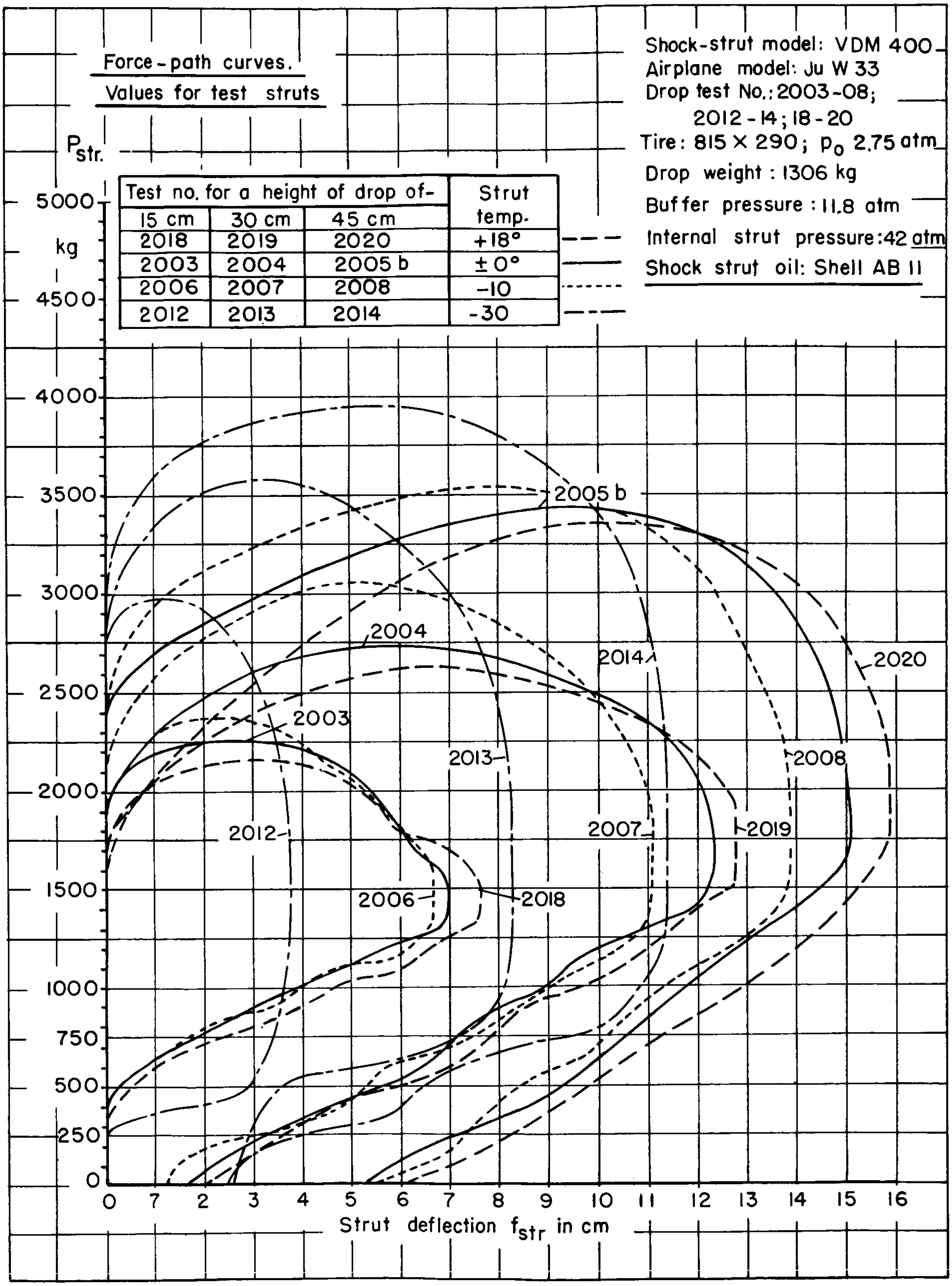
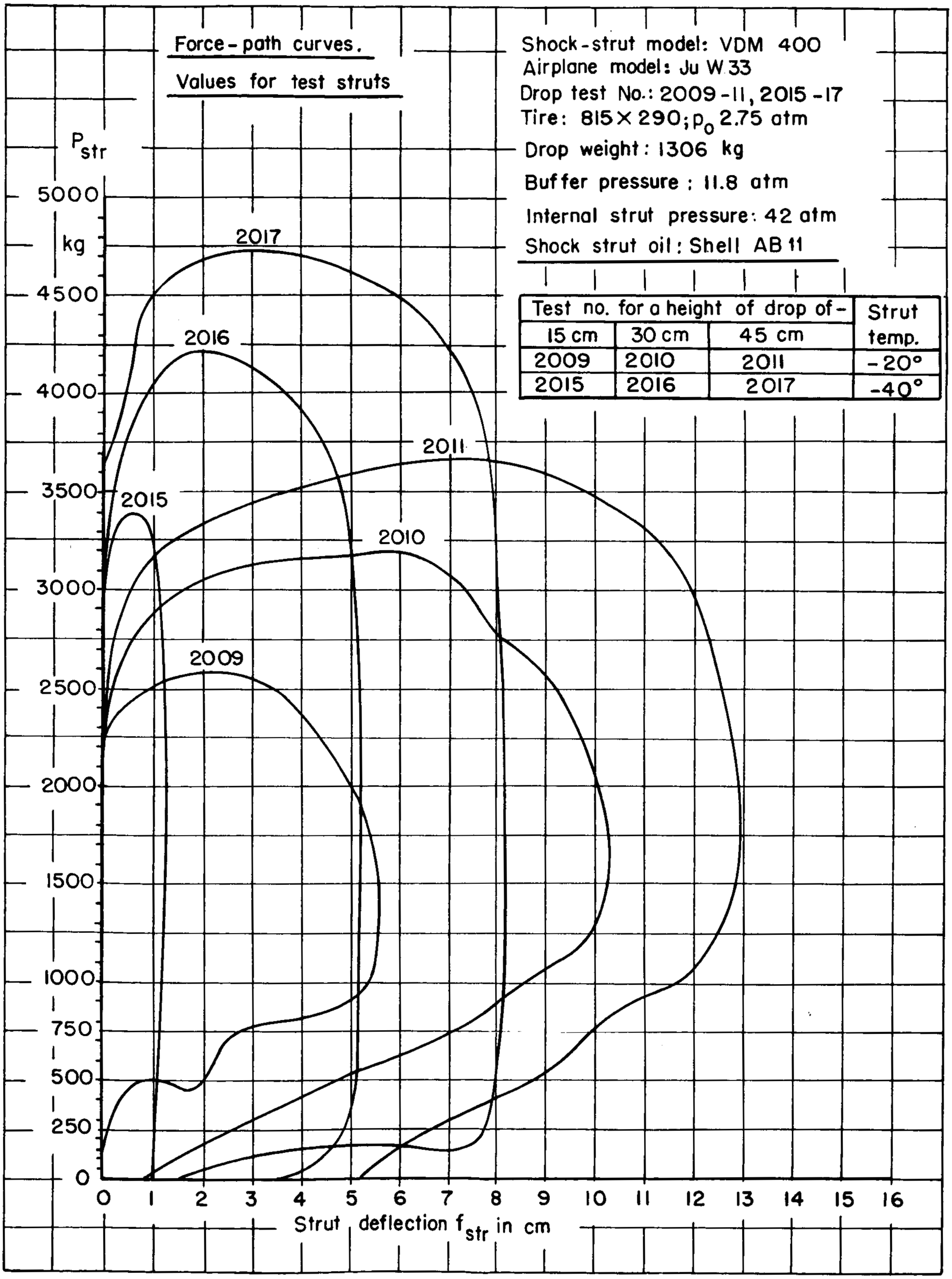


Figure 7.- Test setup for ascertaining the influence of the lubricity of various oil types on the packing friction.



Force-path curves.
Values for test struts
Pstr.
kg
Test no. for a height of drop of-
15 cm
30 cm
45 cm
Strut temp.
2018 2019 2020 +18°
2003 2004 2005 b ±0°
2006 2007 2008 -10
2012 2013 2014 -30
Shock-strut model: VDM 400
Airplane model: Ju W 33
Drop test No.: 2003-08; 2012-14; 18-20
Tire: 815 × 290; p0 2.75 atm
Drop weight: 1306 kg
Buffer pressure: 11.8 atm
Internal strut pressure: 42 atm
Shock strut oil: Shell AB 11
5000
4500
4000
3500
3000
2500
2000
1500
1000
750
500
250
0
2005 b
2004
2014
2020
2003
2013
2008
2012
2007
2019
2006
2018
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Strut deflection fstr in cm

Figure 8



Test no. for a height of drop of -			Strut temp.
15 cm	30 cm	45 cm	
2009	2010	2011	-20°
2015	2016	2017	-40°

Figure 9

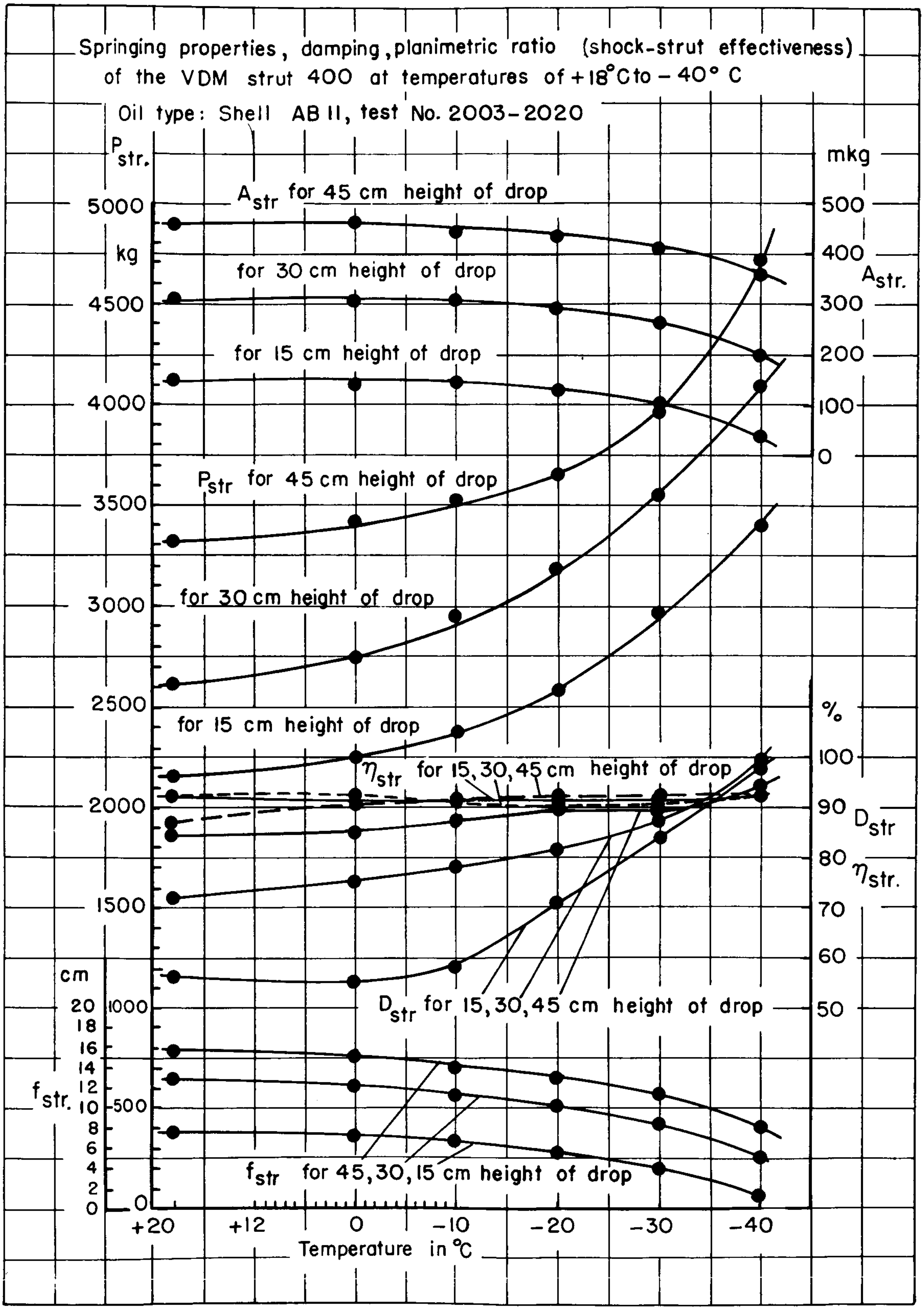

Springing properties, damping, planimetric ratio (shock-strut effectiveness) of the VDM strut 400 at temperatures of +18°C to −40° C
Oil type: Shell AB II, test No. 2003-2020
Pstr.
kg
mkg
Astr for 45 cm height of drop
for 30 cm height of drop
for 15 cm height of drop
Pstr for 45 cm height of drop
for 30 cm height of drop
for 15 cm height of drop
ηstr for 15, 30, 45 cm height of drop
Dstr for 15, 30, 45 cm height of drop
fstr for 45, 30, 15 cm height of drop
Astr.
%
Dstr
ηstr.
cm
fstr.
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
500
400
300
200
100
0
100
90
80
70
60
50
20
18
16
14
12
10
8
6
4
2
0
+20
+12
0
−10
−20
−30
−40
Temperature in °C

Figure 10

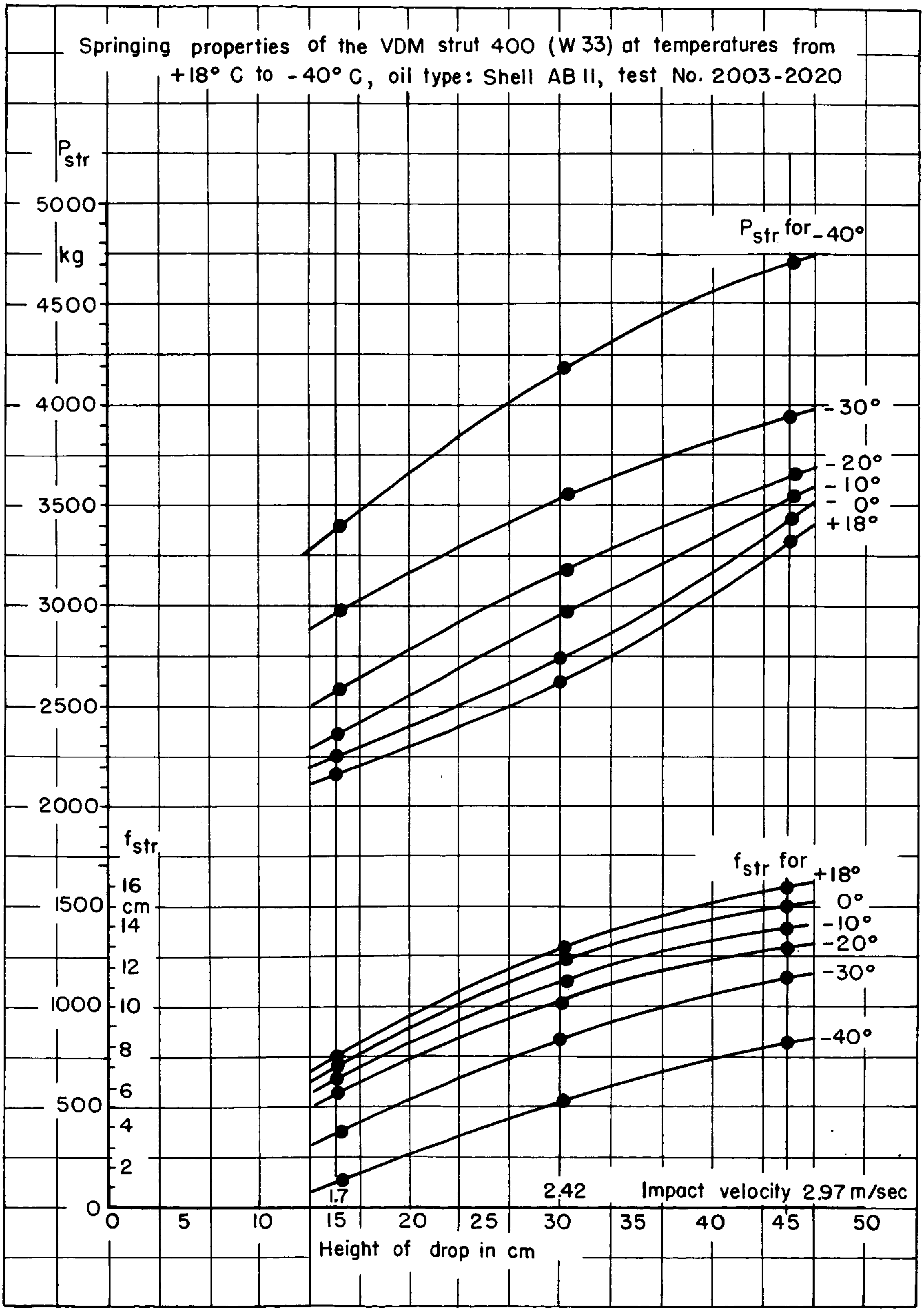
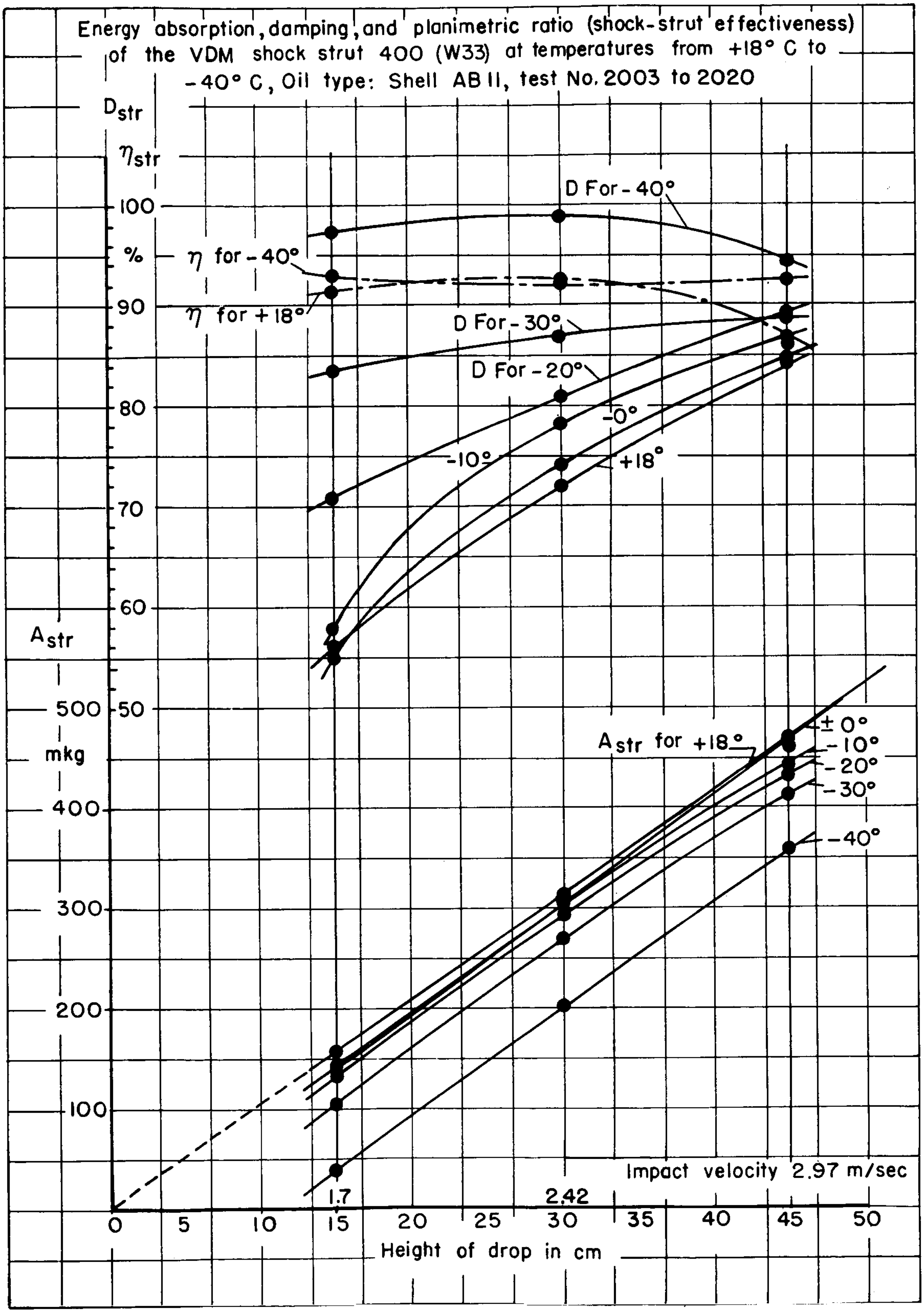

Springing properties of the VDM strut 400 (W 33) at temperatures from +18° C to -40° C, oil type: Shell AB II, test No. 2003-2020
P_{str}
kg
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
P_{str} for -40°
-30°
-20°
-10°
0°
+18°
f_{str}
cm
16
14
12
10
8
6
4
2
f_{str} for +18°
0°
-10°
-20°
-30°
-40°
1.7
2.42
Impact velocity 2.97 m/sec
0
5
10
15
20
25
30
35
40
45
50
Height of drop in cm

Figure 11



Energy absorption, damping, and planimetric ratio (shock-strut effectiveness) of the VDM shock strut 400 (W33) at temperatures from +18° C to -40° C, Oil type: Shell AB II, test No. 2003 to 2020
D_{str}
η_{str}
%
A_{str}
mkg
100
90
80
70
60
50
500
400
300
200
100
D For -40°
η for -40°
η for +18°
D For -30°
D For -20°
-0°
-10°
+18°
A_{str} for +18°
± 0°
-10°
-20°
-30°
-40°
Impact velocity 2.97 m/sec
1.7
2.42
0
5
10
15
20
25
30
35
40
45
50
Height of drop in cm

Figure 12

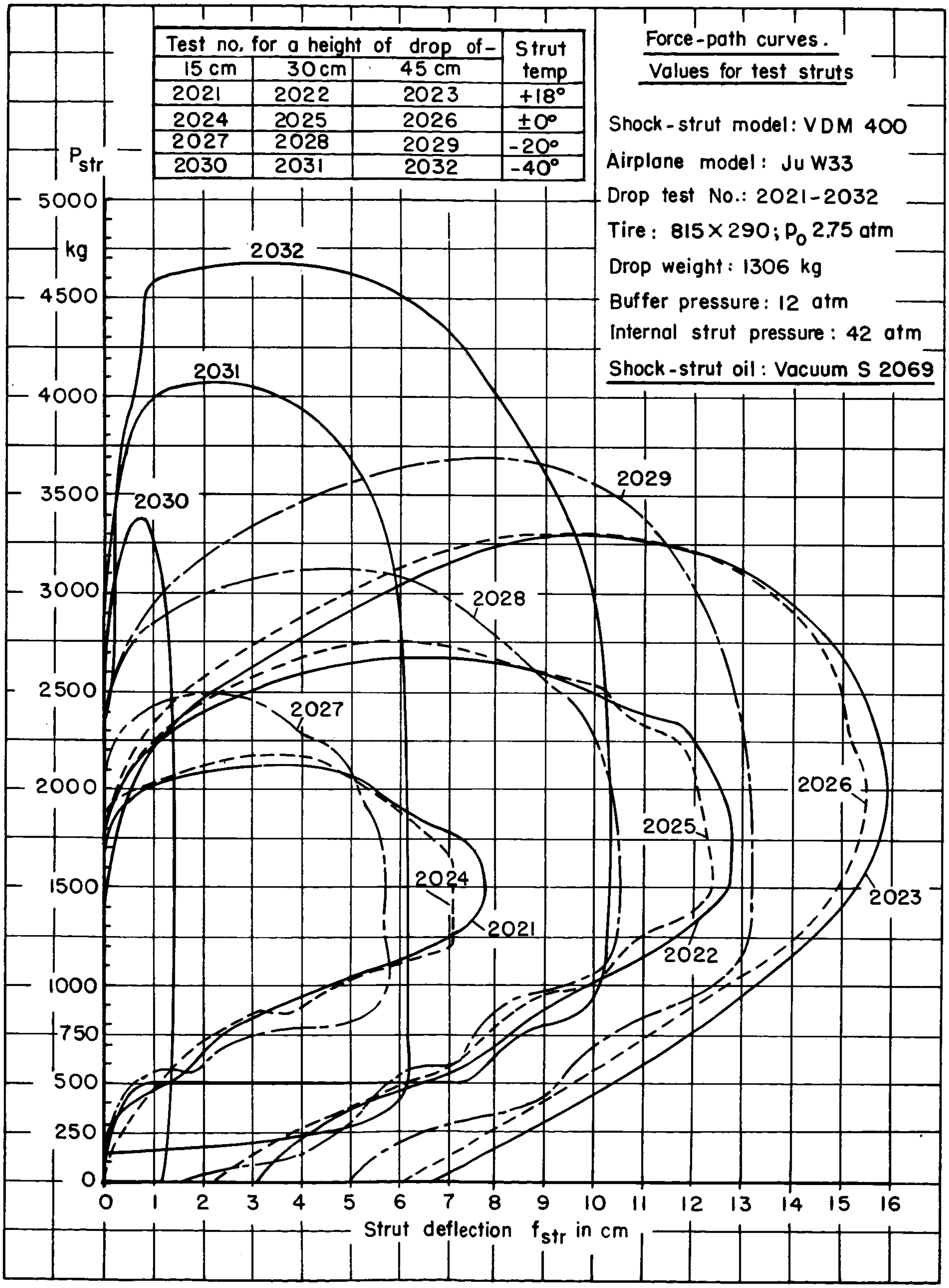

Test no. for a height of drop of–
15 cm
30 cm
45 cm
Strut temp
2021
2022
2023
+18°
2024
2025
2026
±0°
2027
2028
2029
-20°
2030
2031
2032
-40°
Force-path curves.
Values for test struts
Shock-strut model: VDM 400
Airplane model: Ju W33
Drop test No.: 2021-2032
Tire: 815 × 290; p0 2.75 atm
Drop weight: 1306 kg
Buffer pressure: 12 atm
Internal strut pressure: 42 atm
Shock-strut oil: Vacuum S 2069
Pstr
kg
5000
4500
4000
3500
3000
2500
2000
1500
1000
750
500
250
0
2032
2031
2030
2029
2028
2027
2026
2025
2024
2023
2022
2021
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Strut deflection fstr in cm

Figure 13

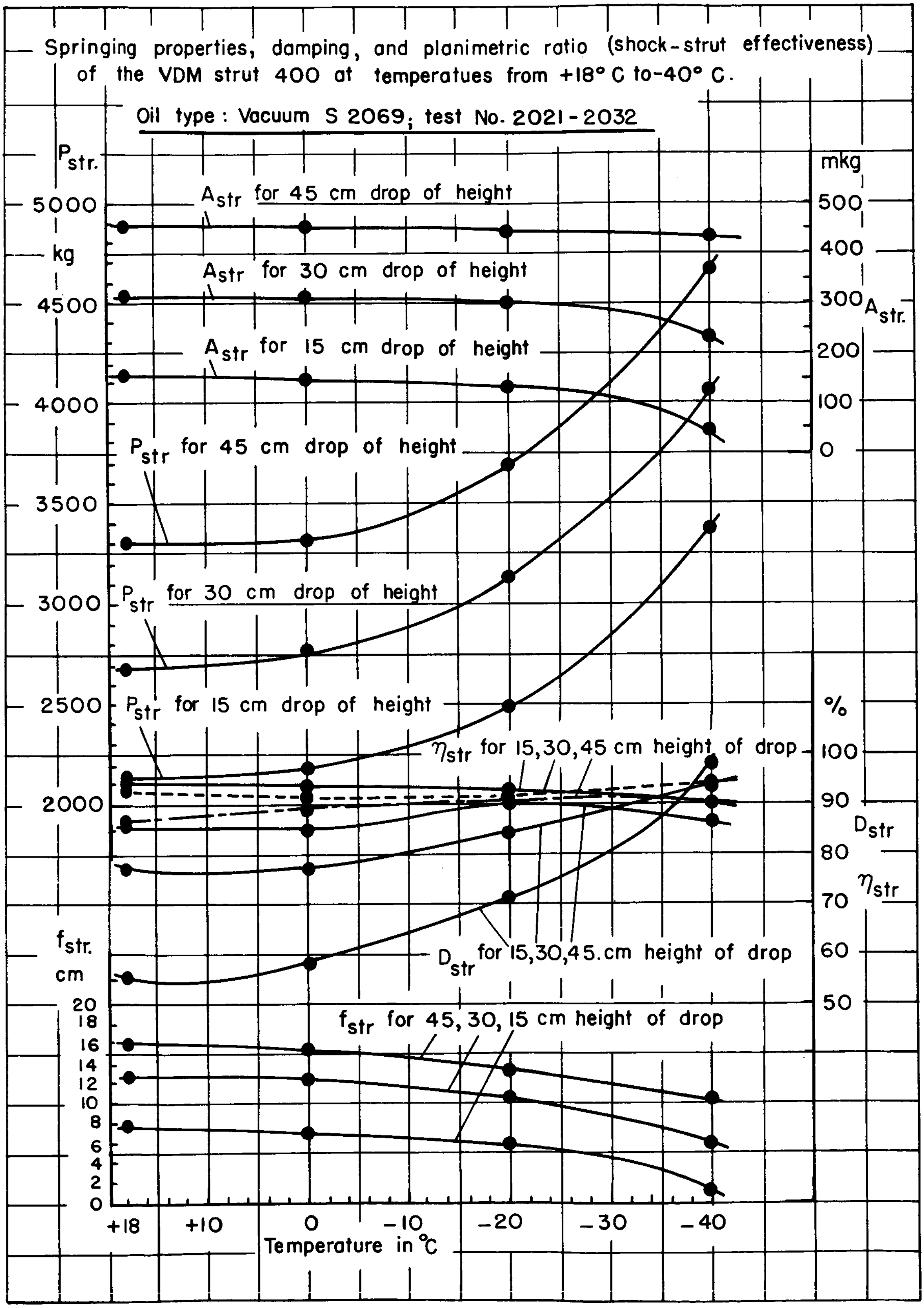

Springing properties, damping, and planimetric ratio (shock-strut effectiveness) of the VDM strut 400 at temperatues from +18° C to-40° C.
Oil type : Vacuum S 2069; test No. 2021-2032
Pstr.
kg
5000
4500
4000
3500
3000
2500
2000
mkg
500
400
300
200
100
0
Astr.
Astr for 45 cm drop of height
Astr for 30 cm drop of height
Astr for 15 cm drop of height
Pstr for 45 cm drop of height
Pstr for 30 cm drop of height
Pstr for 15 cm drop of height
ηstr for 15,30,45 cm height of drop
%
100
90
80
70
60
50
Dstr
ηstr
Dstr for 15,30,45.cm height of drop
fstr.
cm
20
18
16
14
12
10
8
6
4
2
0
fstr for 45, 30, 15 cm height of drop
+18
+10
0
-10
-20
-30
-40
Temperature in °C

Figure 14

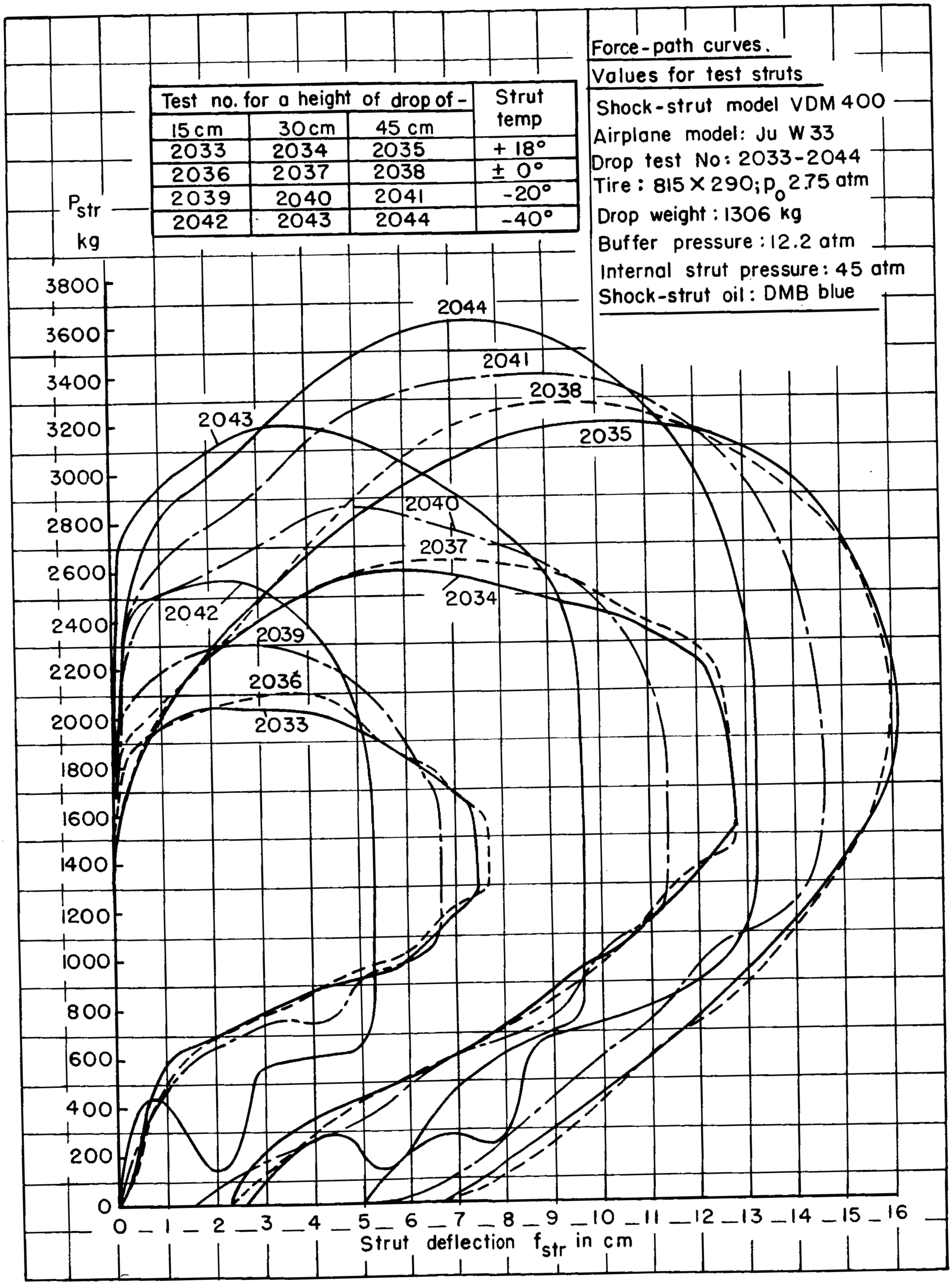
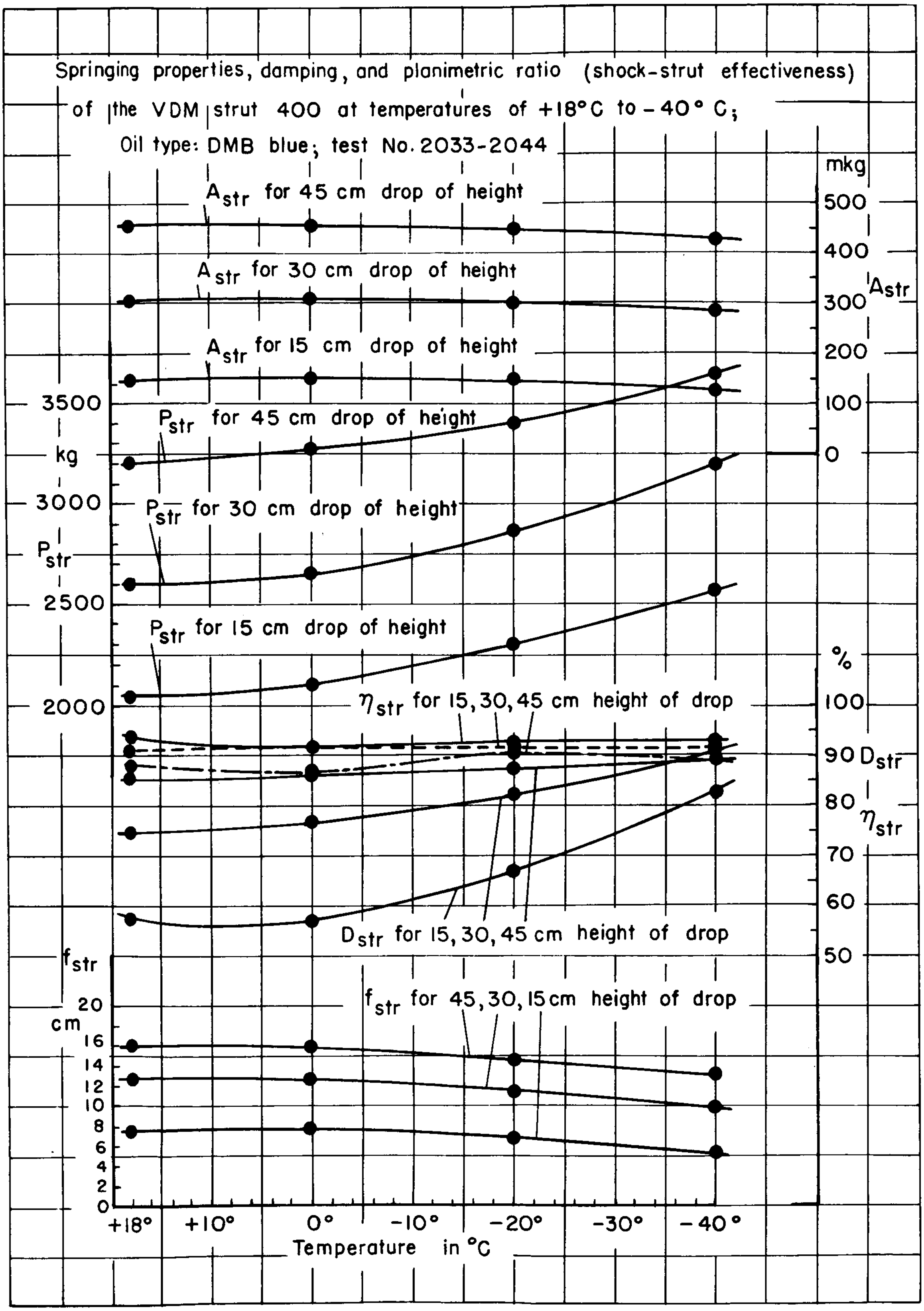

Force-path curves.
Values for test struts
Shock-strut model VDM 400
Airplane model: Ju W 33
Drop test No: 2033-2044
Tire: 815 X 290; p_0 2.75 atm
Drop weight: 1306 kg
Buffer pressure: 12.2 atm
Internal strut pressure: 45 atm
Shock-strut oil: DMB blue
Test no. for a height of drop of -
15 cm
30 cm
45 cm
Strut temp
2033 2034 2035 + 18°
2036 2037 2038 ± 0°
2039 2040 2041 -20°
2042 2043 2044 -40°
P_{str}
kg
Strut deflection f_{str} in cm
2044
2041
2038
2043
2035
2040
2037
2034
2042
2039
2036
2033

Figure 15



Springing properties, damping, and planimetric ratio (shock-strut effectiveness) of the VDM strut 400 at temperatures of +18°C to -40° C;
Oil type: DMB blue; test No. 2033-2044
Astr for 45 cm drop of height
Astr for 30 cm drop of height
Astr for 15 cm drop of height
Pstr for 45 cm drop of height
Pstr for 30 cm drop of height
Pstr for 15 cm drop of height
ηstr for 15, 30, 45 cm height of drop
Dstr for 15, 30, 45 cm height of drop
fstr for 45, 30, 15cm height of drop
mkg
500
400
Astr
300
200
100
0
3500
kg
3000
Pstr
2500
2000
%
100
90 Dstr
80
ηstr
70
60
50
fstr
20
cm
16
14
12
10
8
6
4
2
0
+18°
+10°
0°
-10°
-20°
-30°
-40°
Temperature in °C

Figure 16

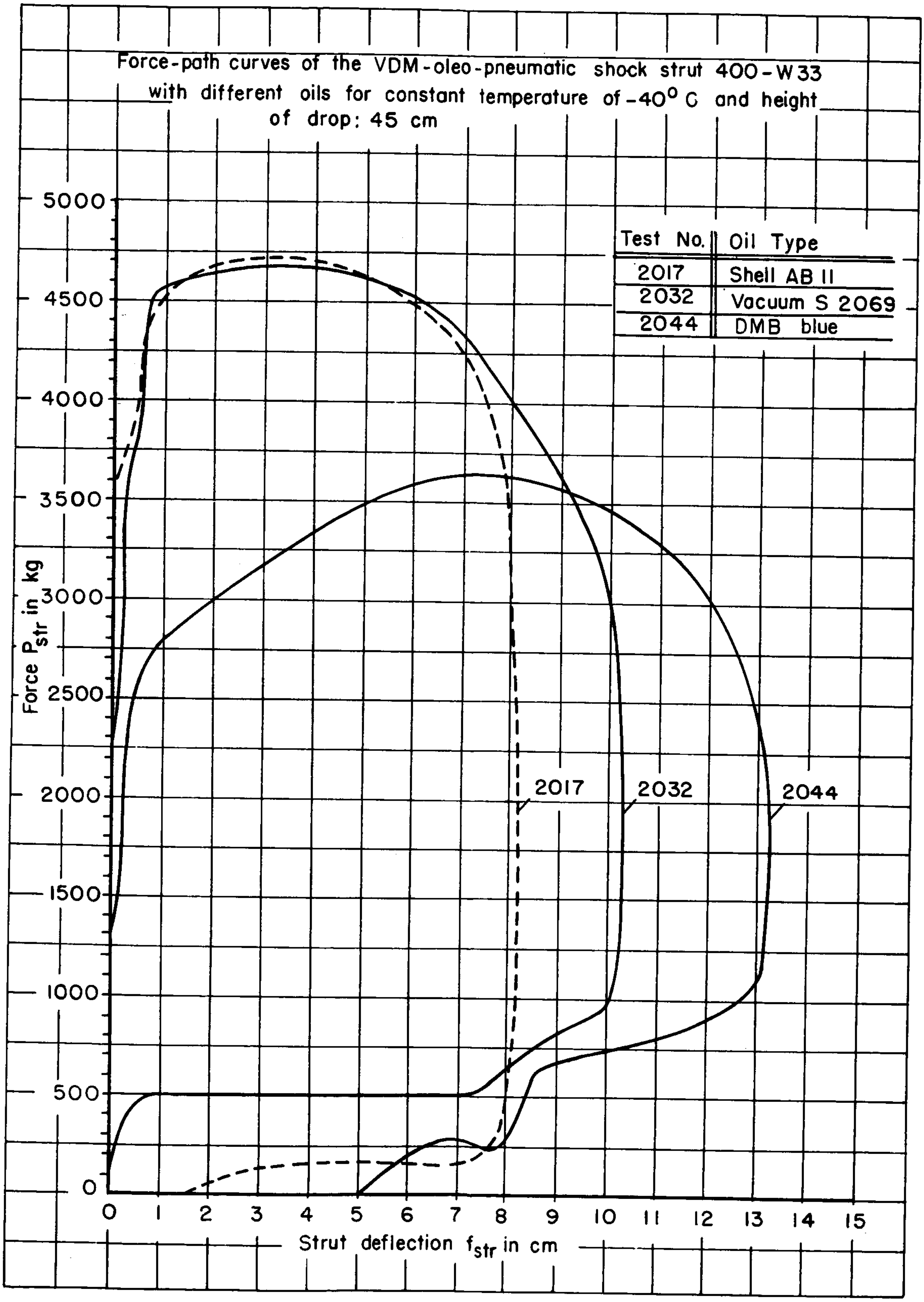

Force-path curves of the VDM-oleo-pneumatic shock strut 400-W33 with different oils for constant temperature of -40° C and height of drop: 45 cm
Test No. | Oil Type
2017 | Shell AB II
2032 | Vacuum S 2069
2044 | DMB blue
Force P_{str} in kg
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2017
2032
2044
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Strut deflection f_{str} in cm

Figure 17

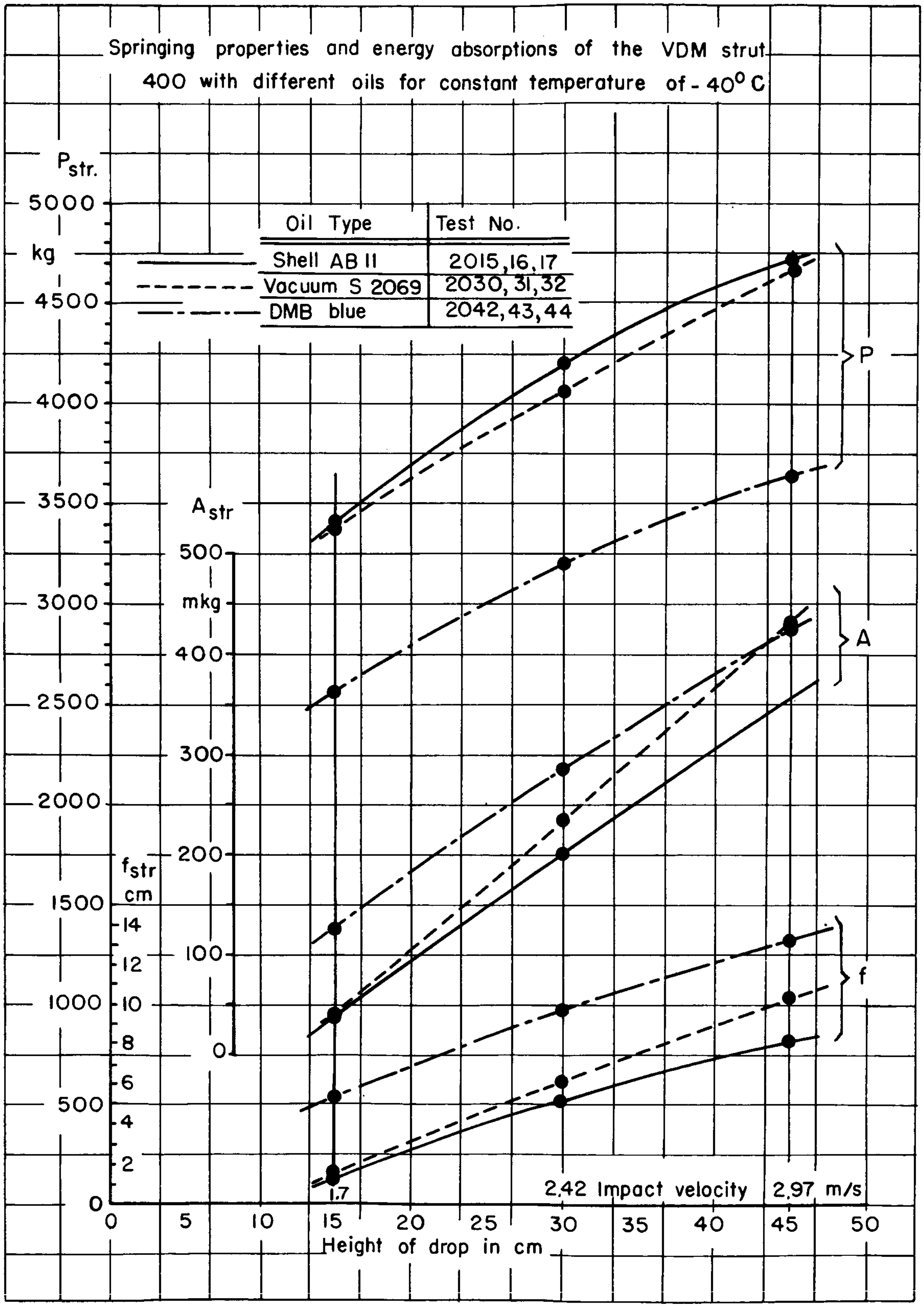

Springing properties and energy absorptions of the VDM strut 400 with different oils for constant temperature of - 40° C
Oil Type | Test No.
Shell AB II | 2015,16,17
Vacuum S 2069 | 2030, 31, 32
DMB blue | 2042,43,44
Pstr.
kg
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Astr
mkg
500
400
300
200
100
0
fstr
cm
14
12
10
8
6
4
2
1.7
P
A
f
2.42 Impact velocity
2.97 m/s
0 5 10 15 20 25 30 35 40 45 50
Height of drop in cm

Figure 18

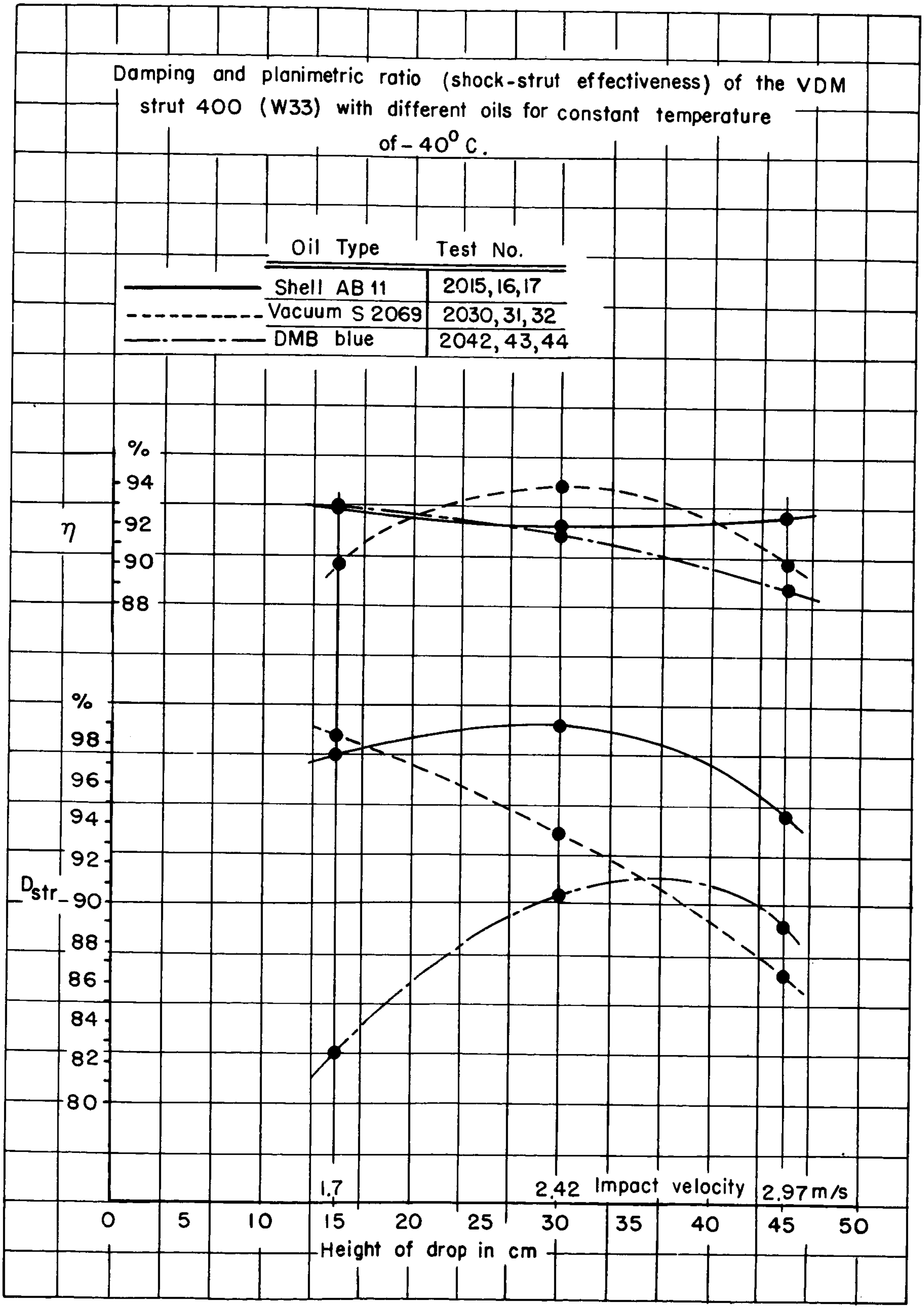

Damping and planimetric ratio (shock-strut effectiveness) of the VDM strut 400 (W33) with different oils for constant temperature of – 40° C.
Oil Type
Test No.
Shell AB 11
2015, 16, 17
Vacuum S 2069
2030, 31, 32
DMB blue
2042, 43, 44
%
94
92
90
88
η
%
98
96
94
92
90
88
86
84
82
80
Dstr
1.7
2.42
Impact velocity
2.97 m/s
0
5
10
15
20
25
30
35
40
45
50
Height of drop in cm

Figure 19

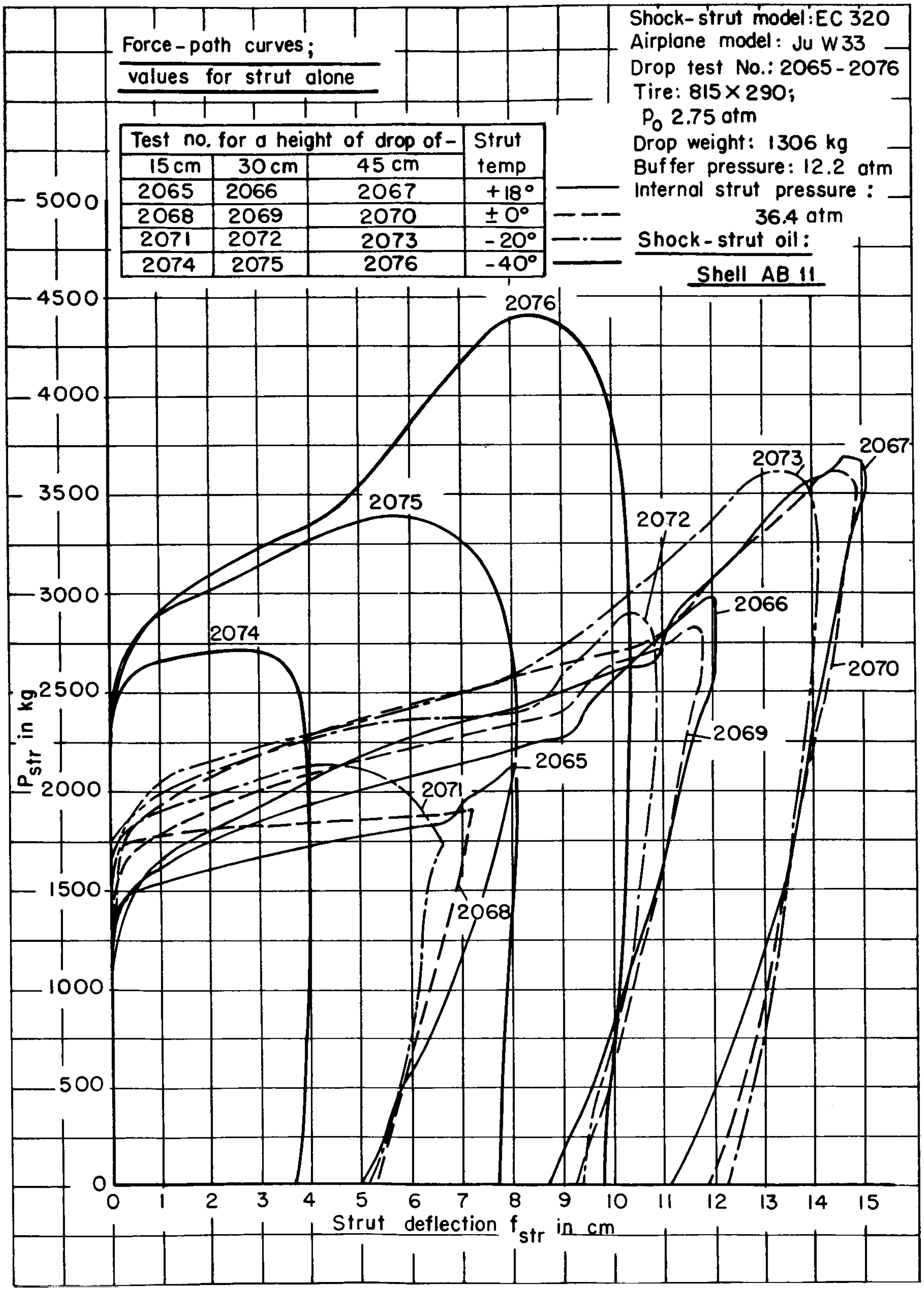

Force-path curves;
values for strut alone
Test no. for a height of drop of-
15 cm
30 cm
45 cm
Strut temp
2065 2066 2067 +18°
2068 2069 2070 ±0°
2071 2072 2073 -20°
2074 2075 2076 -40°
Shock-strut model: EC 320
Airplane model: Ju W33
Drop test No.: 2065-2076
Tire: 815×290;
p_0 2.75 atm
Drop weight: 1306 kg
Buffer pressure: 12.2 atm
Internal strut pressure: 36.4 atm
Shock-strut oil: Shell AB 11
2076
2075
2074
2073
2067
2072
2066
2070
2069
2065
2071
2068
P_{str} in kg
Strut deflection f_{str} in cm
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Figure 20

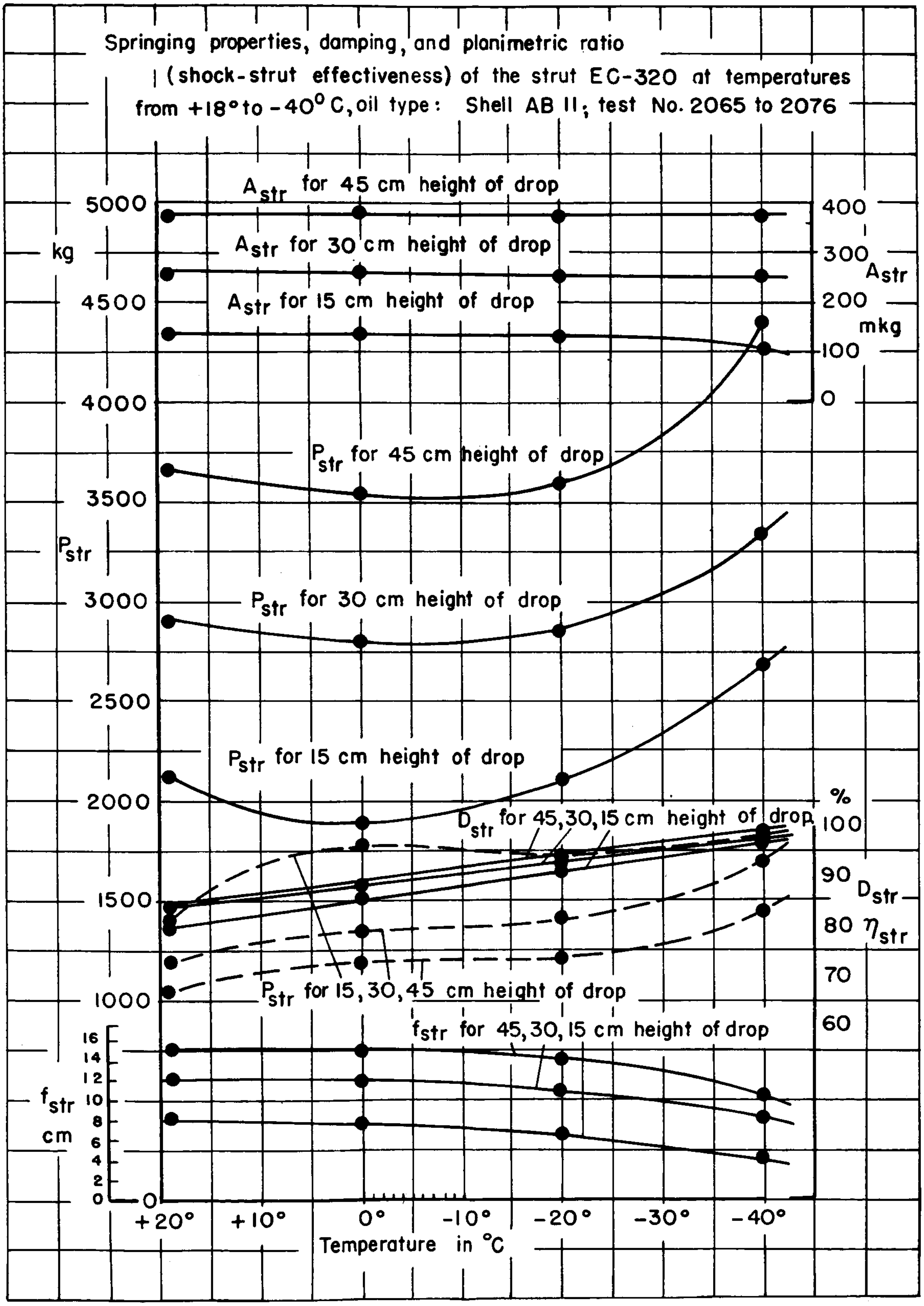
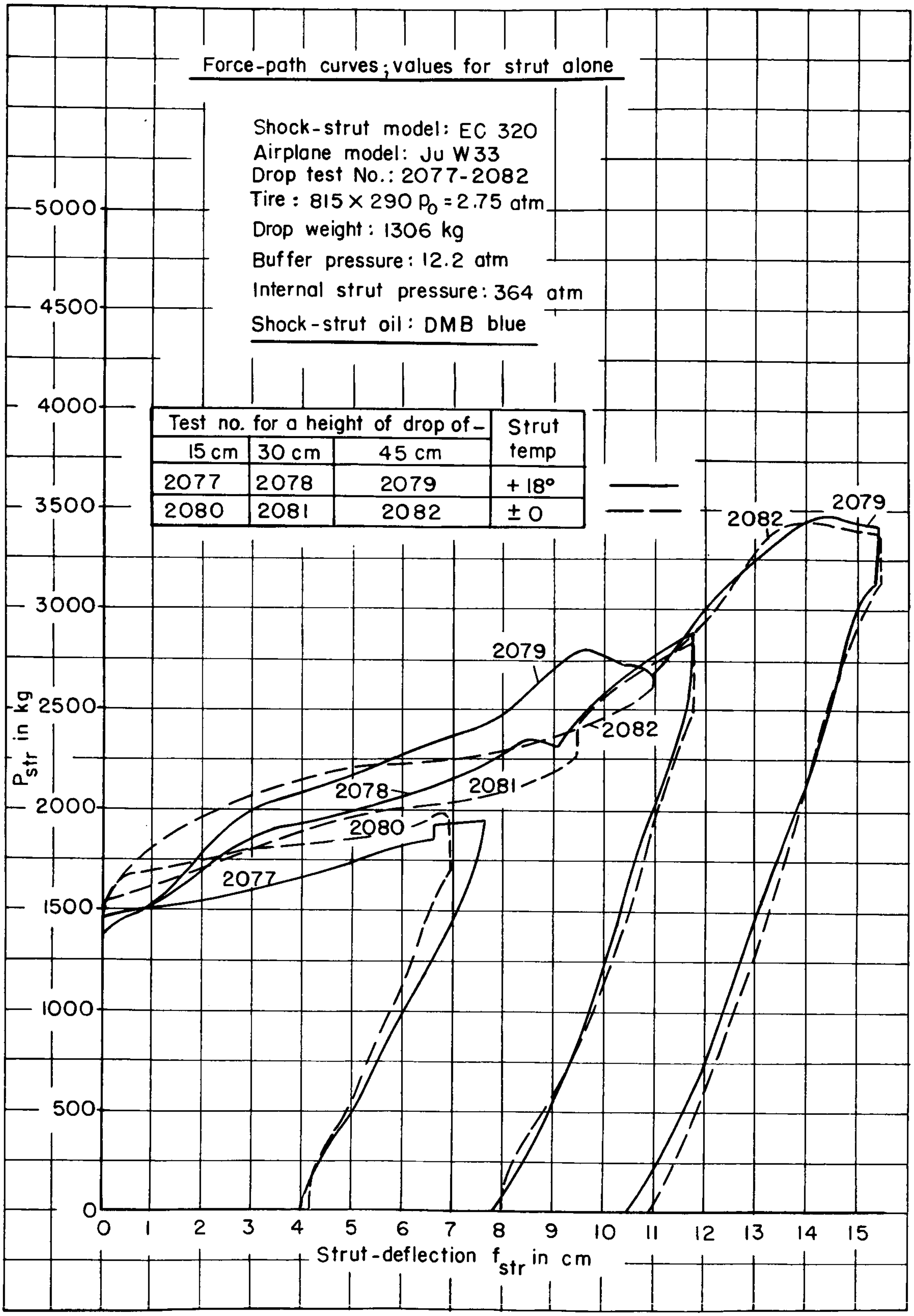

Springing properties, damping, and planimetric ratio
(shock-strut effectiveness) of the strut EC-320 at temperatures
from +18° to -40° C, oil type: Shell AB II; test No. 2065 to 2076
A str for 45 cm height of drop
A str for 30 cm height of drop
A str for 15 cm height of drop
P str for 45 cm height of drop
P str for 30 cm height of drop
P str for 15 cm height of drop
D str for 45, 30, 15 cm height of drop
P str for 15, 30, 45 cm height of drop
f str for 45, 30, 15 cm height of drop
kg
P str
f str cm
A str mkg
%
D str
η str
Temperature in °C

Figure 21



Force-path curves; values for strut alone
Shock-strut model: EC 320
Airplane model: Ju W33
Drop test No.: 2077-2082
Tire: 815 X 290 p_0 = 2.75 atm
Drop weight: 1306 kg
Buffer pressure: 12.2 atm
Internal strut pressure: 364 atm
Shock-strut oil: DMB blue
Test no. for a height of drop of–
15 cm
30 cm
45 cm
Strut temp
2077
2078
2079
+ 18°
2080
2081
2082
± 0
P_{str} in kg
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Strut-deflection f_{str} in cm
2079
2082
2079
2082
2078
2081
2080
2077

Figure 22

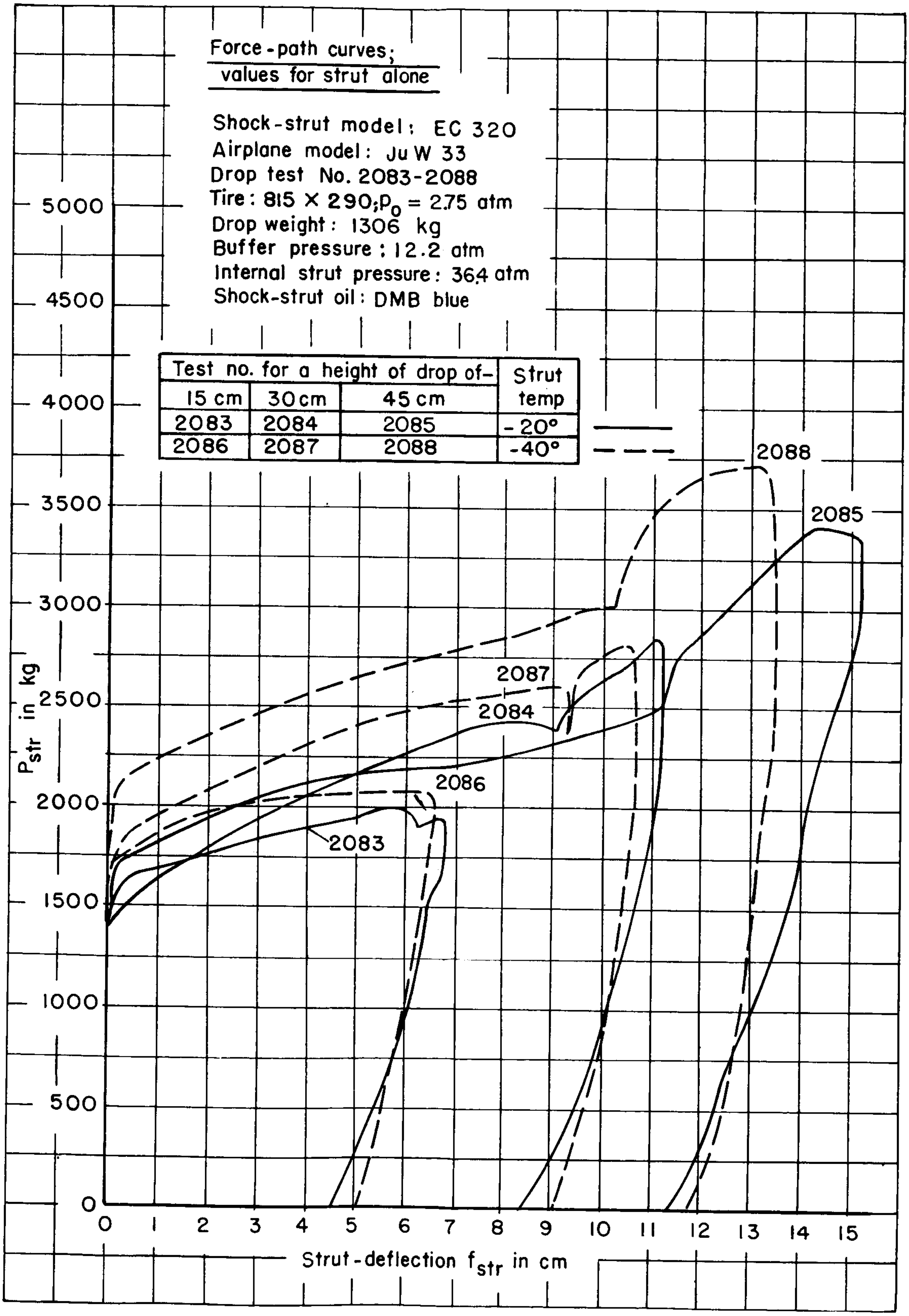

Force-path curves;
values for strut alone
Shock-strut model: EC 320
Airplane model: Ju W 33
Drop test No. 2083-2088
Tire: 815 X 290; p_0 = 2.75 atm
Drop weight: 1306 kg
Buffer pressure: 12.2 atm
Internal strut pressure: 36.4 atm
Shock-strut oil: DMB blue
Test no. for a height of drop of–
15 cm
30 cm
45 cm
Strut temp
2083
2084
2085
-20°
2086
2087
2088
-40°
2088
2085
2087
2084
2086
2083
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
P_{str} in kg
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Strut-deflection f_{str} in cm

Figure 23

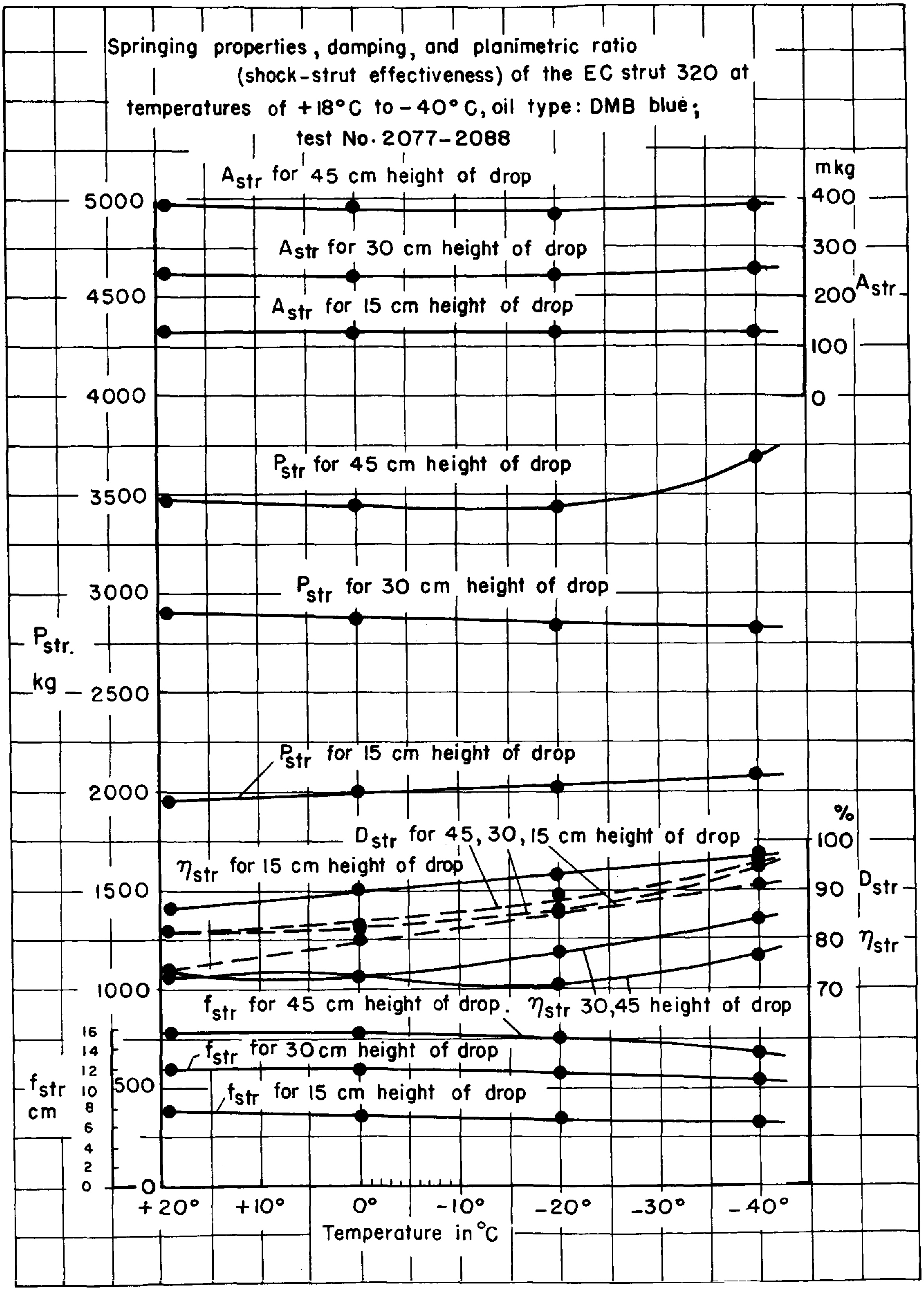

Springing properties, damping, and planimetric ratio (shock-strut effectiveness) of the EC strut 320 at temperatures of +18°C to -40°C, oil type: DMB blue; test No. 2077-2088
A str for 45 cm height of drop
A str for 30 cm height of drop
A str for 15 cm height of drop
P str for 45 cm height of drop
P str for 30 cm height of drop
P str for 15 cm height of drop
D str for 45, 30, 15 cm height of drop
η str for 15 cm height of drop
η str 30,45 height of drop
f str for 45 cm height of drop
f str for 30 cm height of drop
f str for 15 cm height of drop
P str. kg
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
mkg
400
300
200
100
0
A str
%
100
90
80
70
D str
η str
f str cm
16
14
12
10
8
6
4
2
0
+20°
+10°
0°
-10°
-20°
-30°
-40°
Temperature in °C

Figure 24

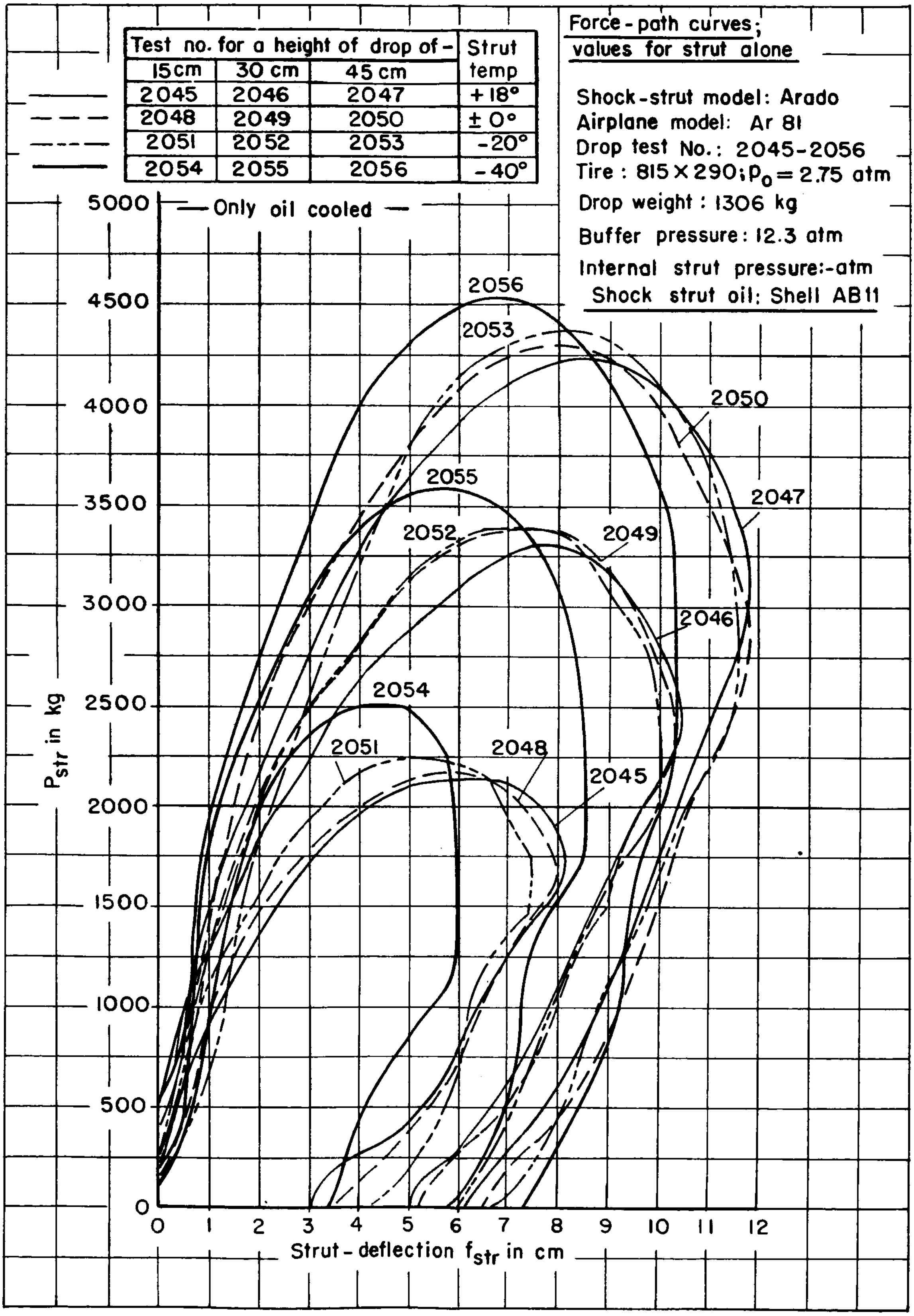

Test no. for a height of drop of -
15 cm
30 cm
45 cm
Strut temp
2045 2046 2047 +18°
2048 2049 2050 ± 0°
2051 2052 2053 -20°
2054 2055 2056 -40°
Force-path curves; values for strut alone
Shock-strut model: Arado
Airplane model: Ar 81
Drop test No.: 2045-2056
Tire: 815 × 290; p_0 = 2.75 atm
Drop weight: 1306 kg
Buffer pressure: 12.3 atm
Internal strut pressure: - atm
Shock strut oil: Shell AB11
Only oil cooled
P_{str} in kg
Strut-deflection f_{str} in cm
2056
2053
2050
2047
2055
2052
2049
2046
2054
2051
2048
2045
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0 1 2 3 4 5 6 7 8 9 10 11 12

Figure 25

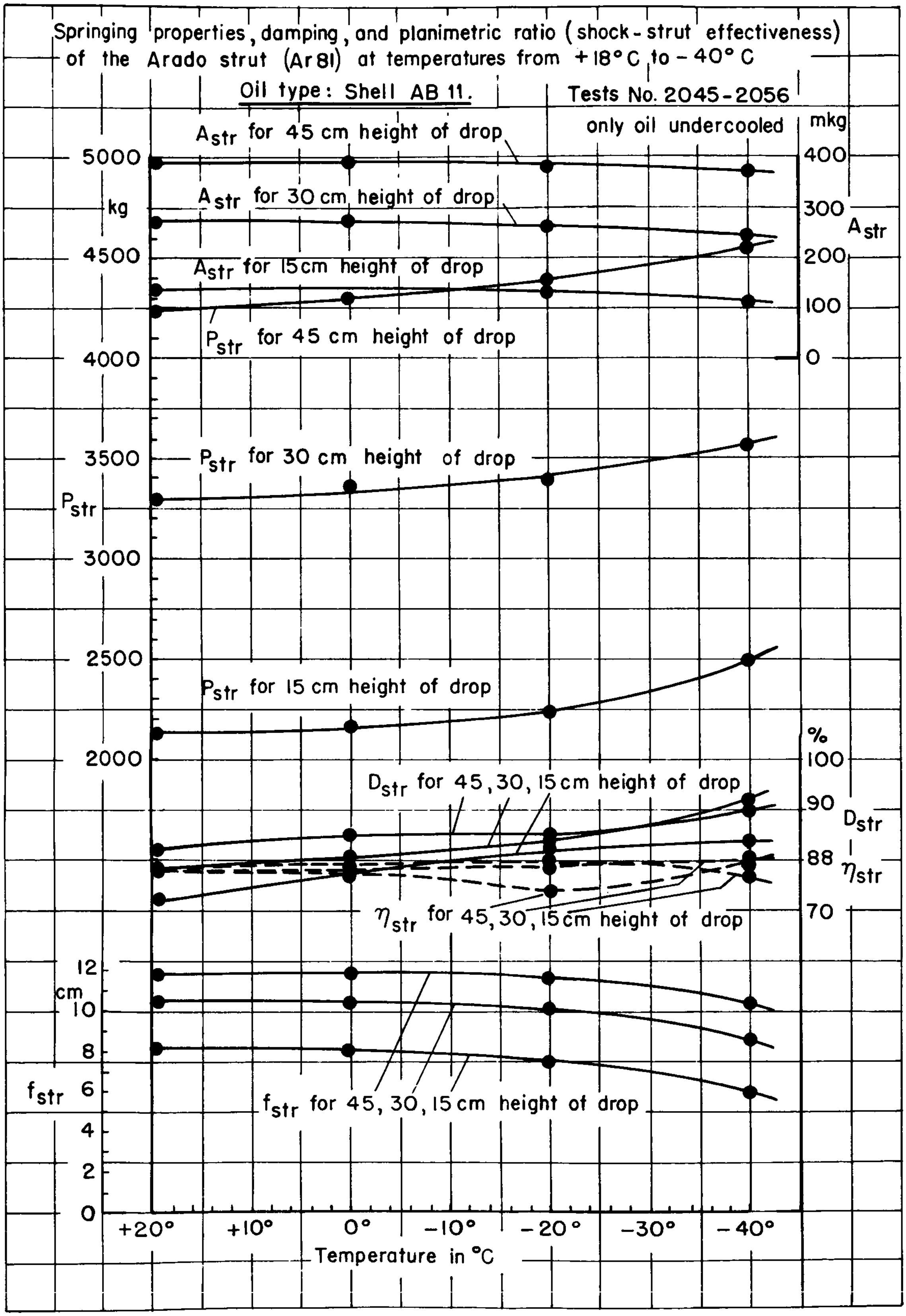

Springing properties, damping, and planimetric ratio (shock-strut effectiveness) of the Arado strut (Ar 81) at temperatures from +18° C to -40° C
Oil type: Shell AB 11.
Tests No. 2045-2056
only oil undercooled
Astr for 45 cm height of drop
Astr for 30 cm height of drop
Astr for 15 cm height of drop
Pstr for 45 cm height of drop
Pstr for 30 cm height of drop
Pstr for 15 cm height of drop
Dstr for 45, 30, 15 cm height of drop
ηstr for 45, 30, 15 cm height of drop
fstr for 45, 30, 15 cm height of drop
5000
kg
4500
4000
3500
Pstr
3000
2500
2000
mkg
400
300
Astr
200
100
0
%
100
90
Dstr
88
ηstr
70
12
cm
10
8
fstr
6
4
2
0
+20°
+10°
0°
-10°
-20°
-30°
-40°
Temperature in °C

Figure 26

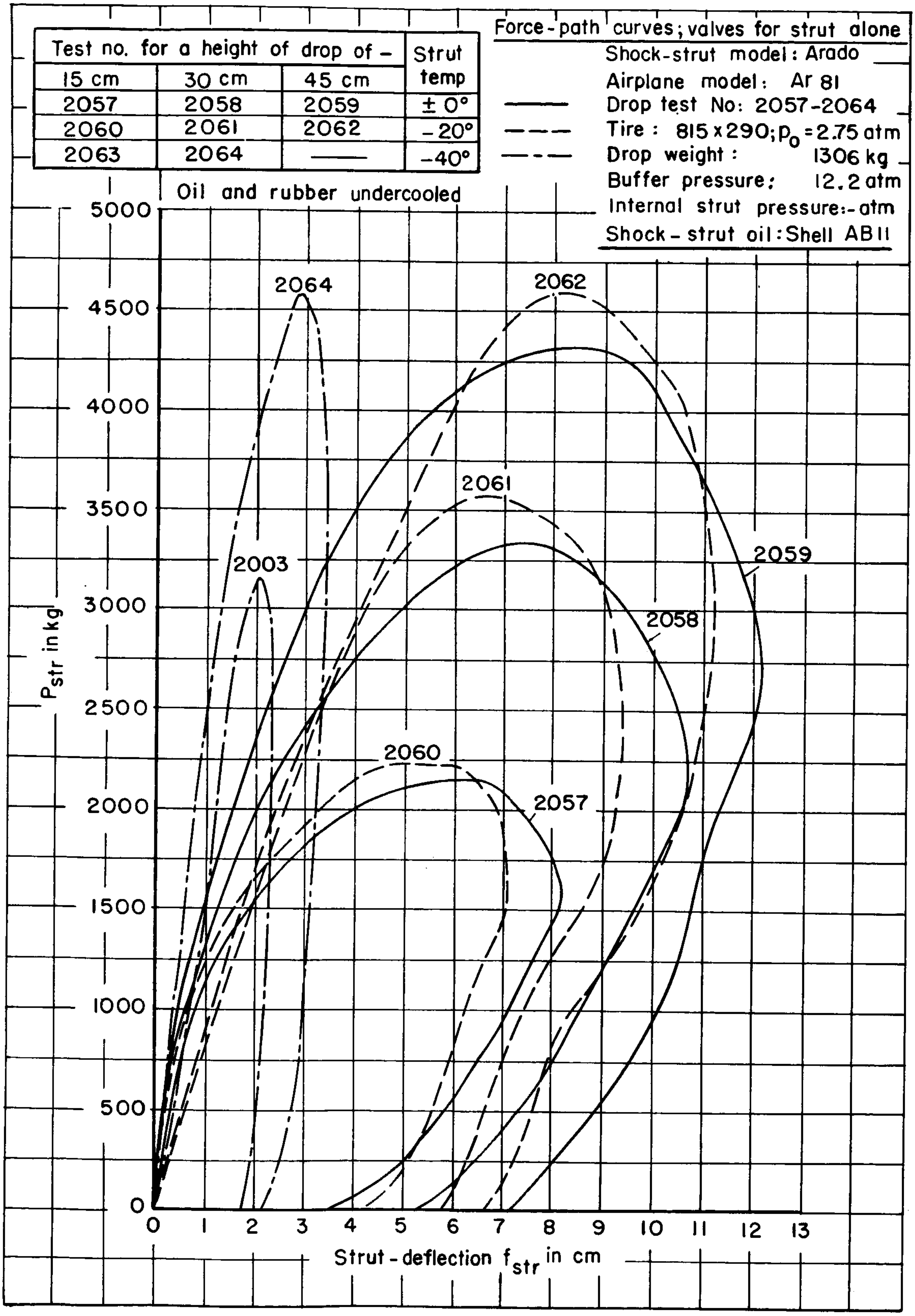

Test no. for a height of drop of –
15 cm
30 cm
45 cm
Strut temp
2057
2058
2059
± 0°
2060
2061
2062
– 20°
2063
2064
–40°
Oil and rubber undercooled
Force-path curves; valves for strut alone
Shock-strut model: Arado
Airplane model: Ar 81
Drop test No: 2057-2064
Tire: 815 x 290; p_0 = 2.75 atm
Drop weight: 1306 kg
Buffer pressure: 12.2 atm
Internal strut pressure: - atm
Shock-strut oil: Shell AB11
2064
2062
2061
2003
2059
2058
2060
2057
P_{str} in kg
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Strut-deflection f_{str} in cm

Figure 27

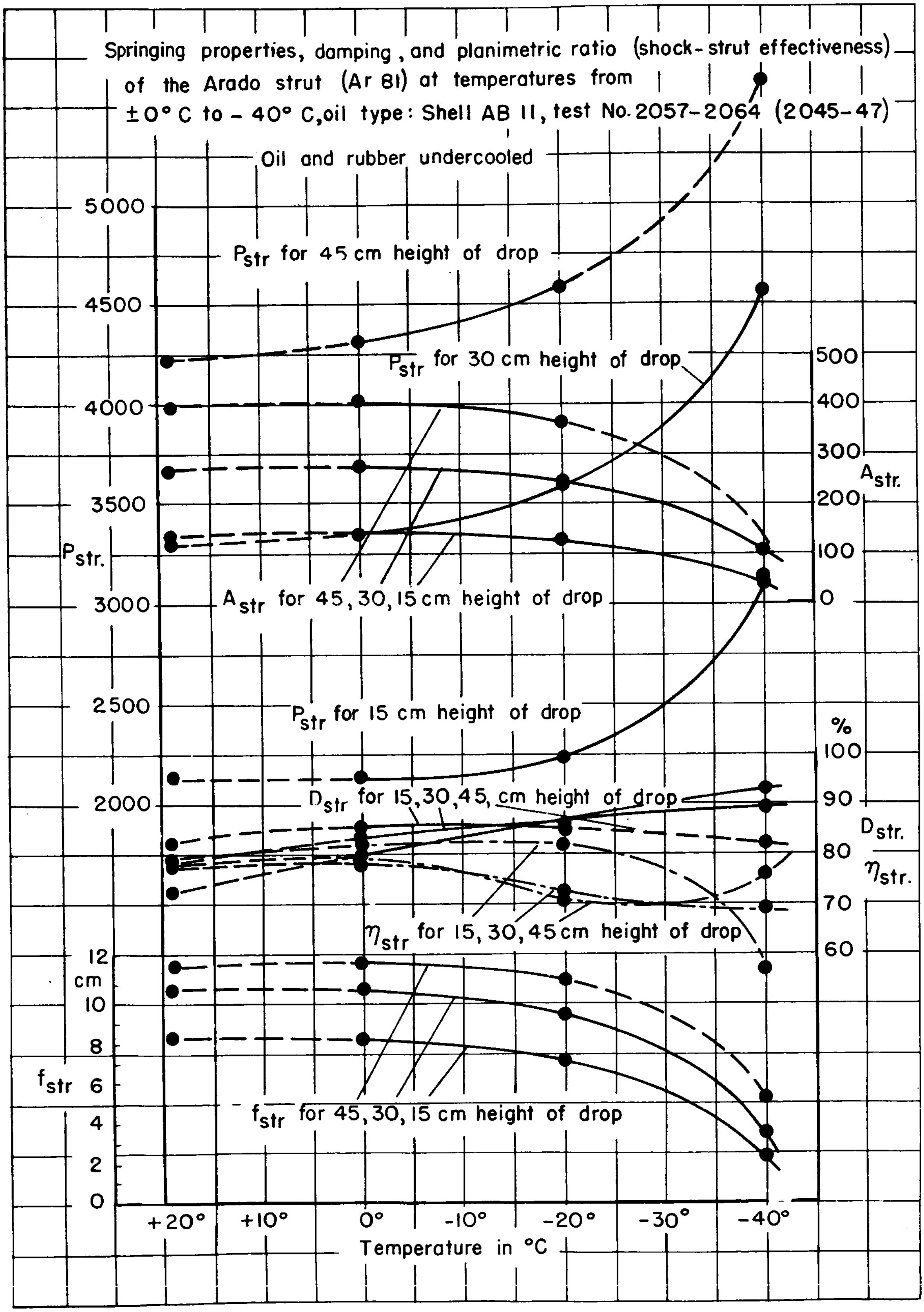

Springing properties, damping, and planimetric ratio (shock-strut effectiveness) of the Arado strut (Ar 81) at temperatures from ±0° C to - 40° C, oil type: Shell AB II, test No. 2057-2064 (2045-47)
Oil and rubber undercooled
P_{str} for 45 cm height of drop
P_{str} for 30 cm height of drop
A_{str} for 45, 30, 15 cm height of drop
P_{str} for 15 cm height of drop
D_{str} for 15, 30, 45, cm height of drop
η_{str} for 15, 30, 45 cm height of drop
f_{str} for 45, 30, 15 cm height of drop
$P_{str.}$
5000
4500
4000
3500
3000
2500
2000
$A_{str.}$
500
400
300
200
100
0
%
100
90
80
70
60
$D_{str.}$
$\eta_{str.}$
12
cm
10
8
f_{str}
6
4
2
0
+20°
+10°
0°
-10°
-20°
-30°
-40°
Temperature in °C

Figure 28

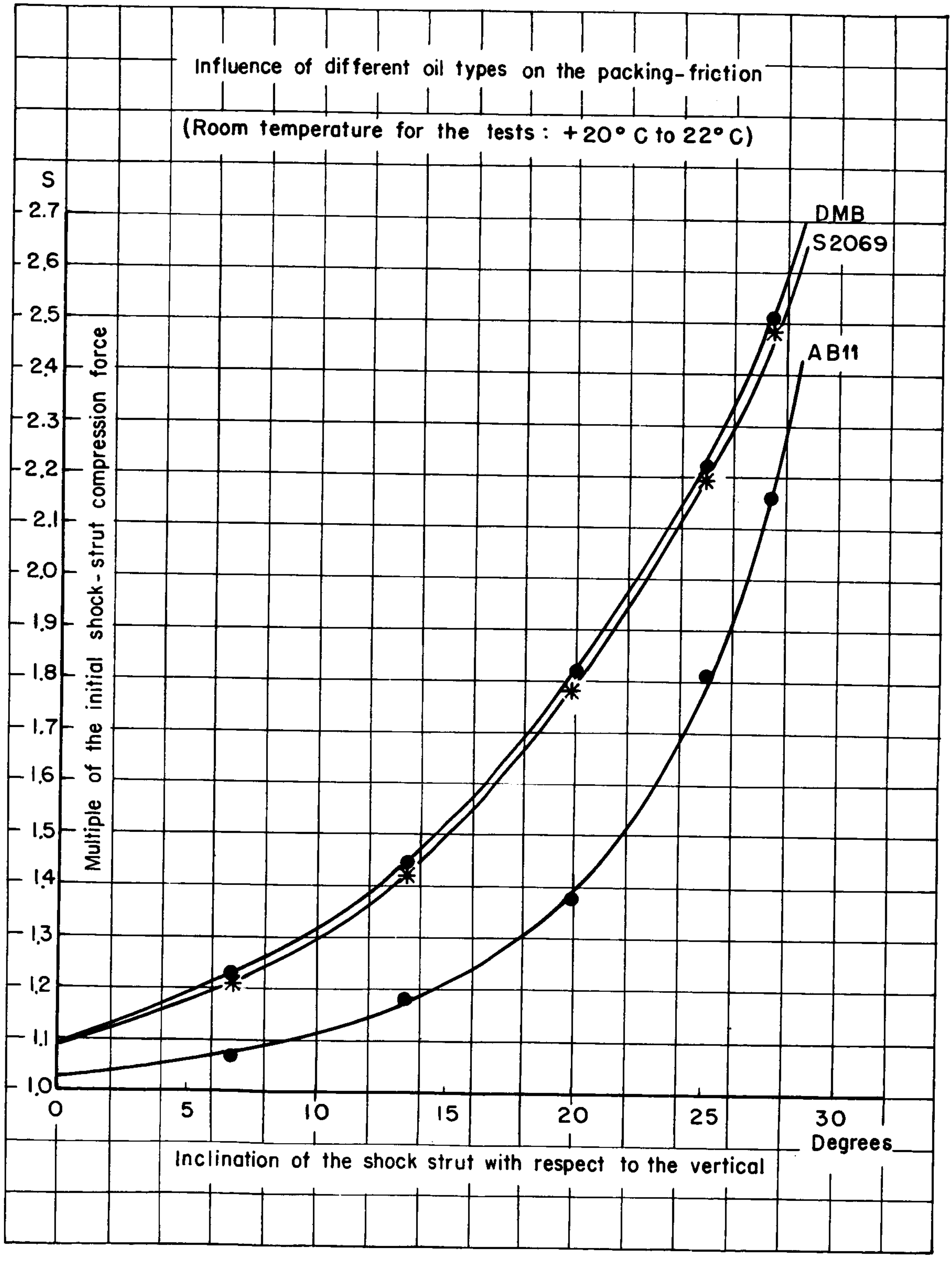

Influence of different oil types on the packing-friction
(Room temperature for the tests : + 20° C to 22° C)
S
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
Multiple of the initial shock-strut compression force
DMB
S2069
AB11
0
5
10
15
20
25
30
Degrees
Inclination of the shock strut with respect to the vertical

Figure 29

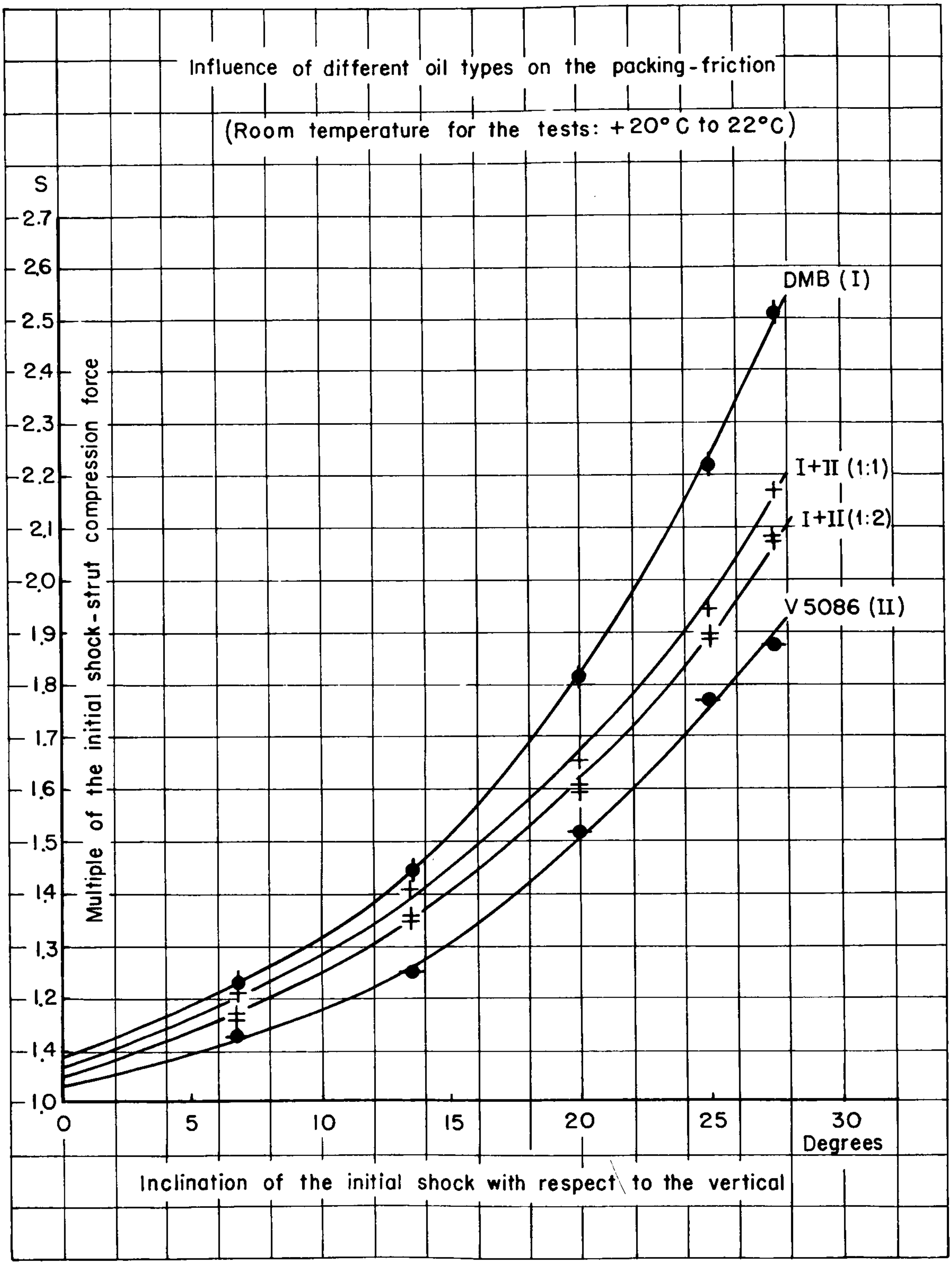

Influence of different oil types on the packing-friction
(Room temperature for the tests: +20° C to 22°C)
S
Multiple of the initial shock-strut compression force
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.4
1.0
0
5
10
15
20
25
30
Degrees
DMB (I)
I+II (1:1)
I+II(1:2)
V 5086 (II)
Inclination of the initial shock with respect to the vertical

Figure 30

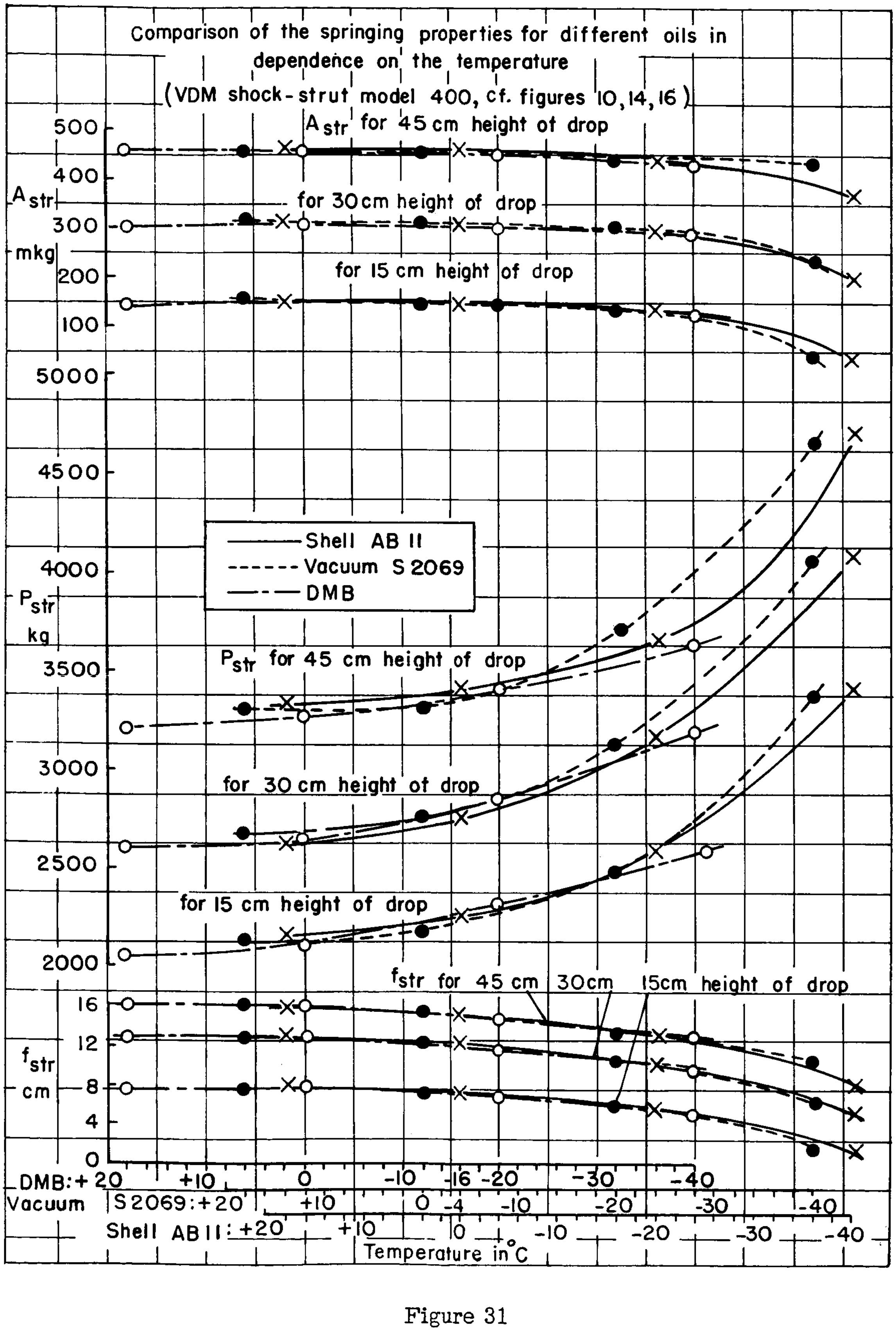

Comparison of the springing properties for different oils in dependence on the temperature
(VDM shock-strut model 400, cf. figures 10, 14, 16)
Astr for 45 cm height of drop
for 30 cm height of drop
for 15 cm height of drop
Astr
mkg
Pstr
kg
fstr
cm
Shell AB II
Vacuum S 2069
DMB
Pstr for 45 cm height of drop
for 30 cm height of drop
for 15 cm height of drop
fstr for 45 cm 30cm 15cm height of drop
DMB: +20 +10 0 -10 -16 -20 -30 -40
Vacuum S2069: +20 +10 0 -4 -10 -20 -30 -40
Shell AB II: +20 +10 0 -10 -20 -30 -40
Temperature in °C

Figure 31

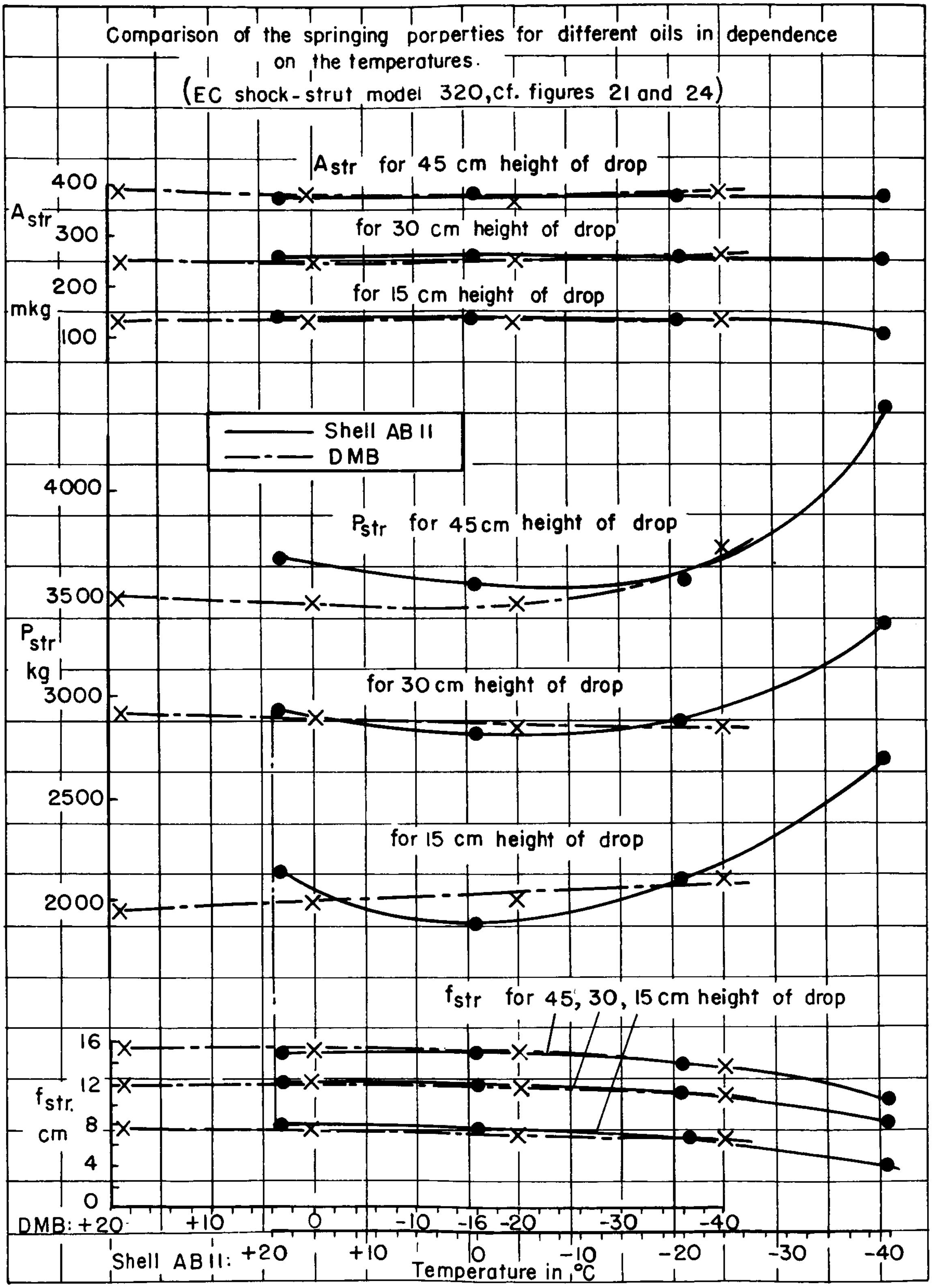
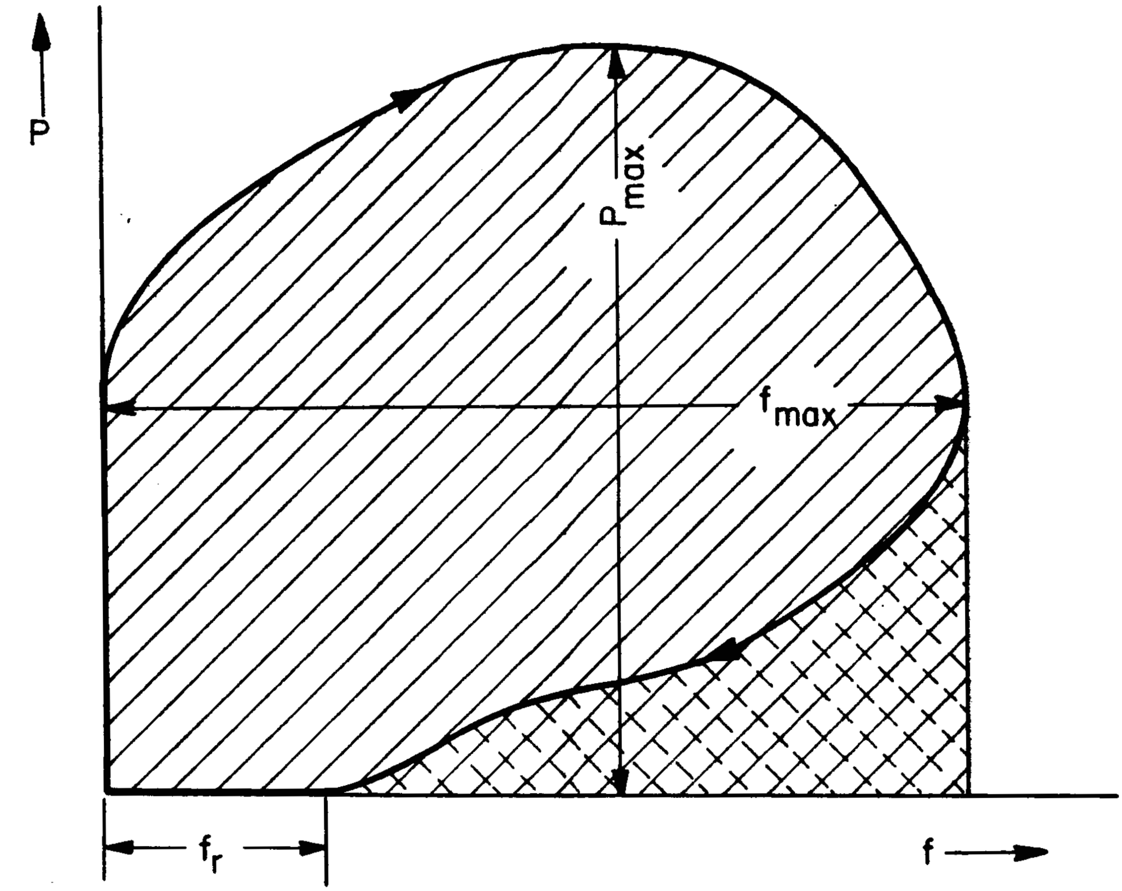

Comparison of the springing porperties for different oils in dependence on the temperatures.
(EC shock-strut model 320, cf. figures 21 and 24)
Astr for 45 cm height of drop
for 30 cm height of drop
for 15 cm height of drop
Astr
mkg
400
300
200
100
Shell AB II
DMB
Pstr for 45cm height of drop
for 30 cm height of drop
for 15 cm height of drop
Pstr
kg
4000
3500
3000
2500
2000
fstr for 45, 30, 15 cm height of drop
fstr
cm
16
12
8
4
0
DMB: +20 +10 0 -10 -16 -20 -30 -40
Shell AB II: +20 +10 0 -10 -20 -30 -40
Temperature in °C

Figure 32



Springing diagram

(Force - path curve of a springing cycle)

Energy absorption : $A = \int_{0}^{f_{max}} P \, df$ (Deflection springing)

Energy return : $A' = \left| \int_{f_{max}}^{f_r} P \, df \right|$ (Return springing)

Damping: $D = \dfrac{A'}{A}$

Maximum force : P_{max}

Maximum deflection of strut : f_{max}

Planimetric ratio: (shock-strut effectiveness) $\eta = \dfrac{A}{P_{max} \; f_{max}}$

Figure 33